Yi-Ming Wei · Hua Liao

Energy Economics: Energy Efficiency in China

Springer

Energy Economics: Energy Efficiency in China

Yi-Ming Wei · Hua Liao

Energy Economics: Energy Efficiency in China

Springer

Yi-Ming Wei
School of Management and Economics, Center for Energy and Environmental Policy Research
Beijing Institute of Technology (BIT)
Beijing
China

Hua Liao
School of Management and Economics, Center for Energy and Environmental Policy Research
Beijing Institute of Technology (BIT)
Beijing
China

ISBN 978-3-319-44629-5 ISBN 978-3-319-44631-8 (eBook)
DOI 10.1007/978-3-319-44631-8

Library of Congress Control Number: 2016948246

The Work is a translation with minor changes and corrections of the book in Chinese “China Energy Report (2010): Energy Efficiency Research” by Yi-Ming Wei and Hua Liao, published by Science Press China (http://www.sciencep.com), ISBN 978-7-03-028838-7.

Printed on acid-free paper

This Springer imprint is published by Springer Nature
The registered company is Springer International Publishing AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Preface

Energy and carbon emissions have become major strategic issues influencing the development pattern of human society and the global political economy.

China is a major player in the production and consumption of energy. With a large population, China is undergoing rapid industrialization and urbanization. Its per capita energy consumption, especially clean energy consumption, is far below that of developed countries; in the future, the total energy demand will continue growing rapidly, and there are uncertainties over the growth rate. China's per capita energy resources, especially quality reserves, are far below the world average; further, with the current level of domestic reserves, it is increasingly difficult to meet the country's economic and social development needs. Energy dependency, especially oil and gas dependency, will continue to climb. Constrained by its development stage and its resource endowments of coal, China's energy development and utilization have caused serious environmental pollution and ecological destruction, negatively influencing human health.

Besides promoting economic development and social progress, China also needs to tackle the new challenges of global climate change and global climate policy. Carbon dioxide emissions are caused by burning fossil fuels; hence, China's energy development faces the difficulty of reducing such emissions, which developed countries have not experienced during their industrialization phase.

The objective of an energy policy is to safeguard supply, protect the environment, and aid in economic growth. Energy conservation and energy efficiency improvement are important and effective ways of responding to these energy challenges.

Energy efficiency is not merely a development issue concerning the natural sciences, engineering, and economic, social, and environmental aspects; it also poses comprehensive, dynamic, and systemic problems in the complex system. This book focuses on research on China's energy efficiency and applies theories and methods in management science and economic science. We hope to be able to enhance the domestic and international energy policy debates and scholarly exchanges about energy economics, as well as provide a reference for China's energy policy and for science and technology professionals in the energy and climate policy fields. Energy and energy efficiency involve several disciplines. With energy economics as the focal point, this book focuses on ten key issues, which are discussed below.

(1) A comprehensive summary and analysis of the world's and China's energy development

Financial crisis, energy prices, climate change, and low-carbon economy are the keywords in global development in the past two years. The year 2010 is the last year for China to complete the "Eleventh Five-Year Plan." It is also the first year when China clarifies its 2020 carbon intensity target. With this background, this book highlights and analyzes the characteristics of global and China's economic development and the energy supply and demand. In particular, it treats the imbalance in energy consumption worldwide, the evolution of energy structure in major countries, the recent changes in global economic and energy development since 2008, progress in the energy conservation and emission reduction in the "Eleventh Five-Year Plan," and major challenges in energy development in China.

(2) The meaning and measure of energy efficiency

For energy efficiency, there exists some misunderstanding or conceptual deviation. From the perspective of energy as a factor of production, this book, in theory, analyzes the relation between energy efficiency and economic systems and the connotation of energy efficiency. From the perspective of factor substitution and structure heterogeneity, this book gives indicators and measurement of energy efficiency, including energy macro-efficiency, physical efficiency, thermodynamics efficiency, value efficiency, allocative efficiency, utilization efficiency, and economic efficiency. This is done using national economic accounting and microeconomics to analyze basic theory, assumed conditions, correlations, advantages and disadvantages, and the effective range of every indication.

(3) Impacts of structural changes in the economy on energy macro-efficiency

Economic structure is an important topic in all governmental conferences it also occupies an important position in China's short-term policies and long-term planning. National and regional energy macro-efficiency levels are quite different; these differences are caused by factors such as the economic structure, technical equipment, energy structure, resource endowments, climate conditions, geographic location, and so on. However, among these factors, the most important is the economic structure. This book uses layered analysis, from endogenous factors to exogenous factors, to study the impacts of industrial structure, consumer structure, and disposition of income structure on China's energy macro-efficiency. Doing so, it examines the direct and indirect effects of urbanization on energy consumption of households.

(4) Analysis of urban, rural, and regional characteristics of residential energy consumption

Since the beginning of the twenty-first century, China's urban and rural residents' living standards have substantially increased, with an increasing demand for energy quantity and quality Nevertheless, the per capita energy consumption is less than 20 % of that of developed countries, and the per capita electricity consumption accounts for 12 % of that of the developed countries. With the continued progress of a well-off society, China's residential energy consumption will continue to grow rapidly. This book analyzes the residential energy consumption characteristics of major countries and differences between urban and rural residential energy consumption and quantitatively analyzes the impact factors of residential energy consumption.

(5) Energy efficiency of key energy-consuming sectors
Energy consumption in the transportation, construction, and power sectors is more than that in other sectors, and the growth rate is fast. This book analyzes the energy consumption characteristics of China's transportation sector, compared with the transportation sectors in the United States, the European Union, and Japan and analyzes domestic and foreign policy relating to energy consumption in the transportation sector. The book also analyzes China's energy consumption in the transportation sector and energy efficiency in the power sector in terms of the transmission and distribution aspects and other issues.

(6) In-depth analysis of the impact of prices on oil demand
With China's recent rapid economic growth, demand for oil is at record highs. From the early twenty-first century to the global financial crisis in 2008, the international price of oil has increased significantly; thus, although not technically accurate, it was believed that a higher oil price would lead to an increasing demand for oil and that rising oil prices did not have any effect on energy conservation. This book quantitatively studies the impact of oil prices on the demand for crude oil.

(7) Comparison of China's regional energy efficiency
China's regional development is uneven, and energy efficiency among its regions varies. Coordinating its regional development is an important aspect of its current and future development policies. At the beginning of the "Eleventh Five-Year Plan", the target was to decrease energy consumption per unit of GDP by 20 % compared with 2005, and then the target is decomposed into regions. At present, China is working to develop the "Twelfth Five-Year Plan", and, the energy conservation and carbon reduction plans on both the national and local district levels by 2020. Comprehensively understanding the differences and changes in the direction and speed of differences of energy efficiency and distinguishing between the subjective and objective reasons for these differences are the preconditions for developing a national and regional energy-saving, emission reduction plan. It is also the precondition for a scientific evaluation of energy-saving performance. In this context, this book empirically analyzes regional energy efficiency.

(8) A comprehensive analysis of energy efficiency policies in developed countries and its implications for China
Since the first oil crisis of the 1970s, developed countries have accumulated more experience and established near-perfect energy efficiency policies. In the 35-year

period (1974–2009), the IEA member countries have experienced overall economic growth of 144 % while energy intensity decreased by 41 %, especially caused by the change in national energy efficiency. This book compares the energy efficiency policies of Japan, the European Union, and the United States, including relevant laws and regulatory, fiscal, taxation, and technology policies, and then it analyzes the implications for China.

(9) Simulation and policy analysis of end-use energy efficiency policies
Investment in improving energy efficiency can reduce the source cost of services. In the absence of additional energy and environmental policy constraints, the efficiency of energy use will be accompanied by a rebound effect that must be at least partially offset by the initial energy savings. This book examines the end-use energy efficiency and the country's economic growth, energy use, and carbon dioxide emissions, focusing on the rebound effect and the various energy and environmental policies in place.

(10) Analyses of the energy efficiency opportunities in China
As the rate of China's energy consumption shows an exponential growth, energy efficiency has never been so urgent and important. China's future energy efficiency direction—whether energy consumption per unit of GDP will maintain its downward trend or whether the emission reduction target, that is, the carbon emission per unit of GDP falling by 40–45 % in 2020 compared with 2005, will be achieved—urgently needs to be explored. This book analyzes the historic opportunities for China's energy, improvement, and judgments on its energy macro-efficiency trend as based on an international comparison.

To be better able to contribute to scientific research, personnel training, and international communication of energy and environmental policy, in 2006, I coordinated with Prof. Yongfa Xu and Keyu Liu to establish the Center for Energy and Environmental Policy Research (CEEP), and I took charge as the first chief. In 2009, the Beijing Institute of Technology President, Haiyan Hu, and the party secretary of Prof. Dacheng Guo invited me and core members of my team to join the Beijing Institute of Technology. The Beijing Institute of Technology's President Office approved the establishment of CEEP in Beijing Institute of Technology, anchored at the School of Management and Economics.

The overall deployment of this project was conducted under the leadership of Prof. Yi-Ming Wei. Further, Hua Liao, Qiao-Mei Liang, Wen-Jing Yi, Zhen-Hua Feng, Jing-Li Fan, Zhong-Yuan Ren, Bin Ouyang, Hai-Bo Wang, Gang Wu, Li Liu, and Jian-Lei Mo participated and completed the relevant sections of this book. Le-Le Zou, Xiao-Wei Ma, Yue-Jun Zhang, Zhi-Yong Han, Jiu-Tian Zhang, Xu-Mei Chen, Jiao-Ling Jiao, Bin Fang, Jie Guo, Kang Li, Zhi-Fu Mi, Kai Wang, Liang-Qiong Xiong, Rui-Guang Yang, Yun-Fei Yao, Ying Yuan, Rong-Gang Cong, Mei-Ning Duan, Lu-Tao Zhao, etc., participated in the study, discussions, and proofreading of sections of this book. The book is the collective wisdom of CEEP. During the process of publication of this book, we have sought to update the relevant data. Although some studies were completed 2 or 3 years ago and some data are not complete, the conclusions of the study and judgment have proved to be correct and have stood the test of time and practice.

During the researching and writing of this book, we received support from the National Natural Science Foundation (Nos. 71521002, 71673026, 71322306 and 71273027), the National Key R&D Program (Nos. 2016YFA0602603 and 2016YFA0602801) as well as encouragement, guidance, support, and selfless help from experts and officials, including Shupeng Chen (academician), Zhongli Ding (academician), Xiangwan Du (academician), Jinghai Li (academician), Suping Peng (academician), Chongqing Guo (academician), Jingwen Li (academician), Shanlin Yang (academician), Qidi Wu, Yanhua Liu, Dingming Xu, Yin Wu, Jingyuan Yu, Jiankun He, Siqiang Wang, Weixuan Xu, Jianguo Song, Yanhe Ma, Jing Huang, Wen Song, Fengquan An, Hong Sun, Shantong Li, Xiaotian Chen, Jizhong Zhou, Yijun Li, Shouyang Wang, Ziyou Gao, Wei Zhang, Haijun Huang, Liexun Yang, Zuoyi Liu, Ruojun Li, Gao Li, Yande Dai, Shixian Gao, Huaqing Xu, Yanbing Kang, Jianping Liu, Keyu Liu, Chengchuan Tian, RIsheng Guo, Sizhen Peng, Xiaofeng Fu, Jingming Li, Xuyan Tu, and Jianmin Zhang. Our overseas colleagues, including Tol R.S.J., Hofman B., Martinot E., Drennen T., Jacoby H., Parsons J., MacGill I., Edenhofer O., Burnard K., Nielsen C., Nguyen F., Okada N., Ang B., Yan J., Tatano H., Chou S. K., Huang Z. M., Murty T., Yang Z. L., and Erdmann G. were invited to visit the Center. Zhongli Ding, member and vice-president of the Chinese Academy of Sciences, guided and supported us in studying “Energy Economics”. They gave us great support and assistance, and we express our sincere appreciation to them.

We take this opportunity to specially thank Prof. Changlu Zhao (Party Secretary of Beijing Institute of Technology), academician Haiyan Hu (President of Beijing Institute of Technology), and other school leaders. We would like to express thanks for the support and help of the leaders of school functional departments and colleagues of School of Management and Economics. Without their support and assistance, it would have been difficult to publish this book in such a short period of time, to adapt to the new working environment, to and concentrate on the completion of the follow-up study.

Thanks to all the authors of the documents referenced in this book!

Due to our limited knowledge of the style and norms of academic-level publications, the book may inevitably be flawed and inadequate in some instances (even wrong), and we are open to criticism and correction!

Beijing, China Yi-Ming Wei
July 2016

Contents

1 Energy Development in the World and China 1
1.1 World Energy Development Review. 2
1.1.1 World Economy and Energy Consumption Are Significantly Correlated When Taking a Statistical Perspective 2
1.1.2 Different Energy Demand Elasticities of GDP in Different Development Stages 3
1.1.3 Different Decreasing Rates of Energy Intensity Across Countries 4
1.1.4 There Is no Significant Improvement in the World's Unbalanced Energy Consumption 5
1.1.5 Energy Poverty and the Induced Health Issues Are Still Serious 6
1.1.6 World Energy Trade Increases Steadily and Natural Gas Emerges Progressively 6
1.1.7 Fossil Fuel-Based Energy Consumption Has Caused Serious Pollution Are Carbon Emissions. 10
1.2 New Trends of World Energy Development from 2008 to 2010 12
1.2.1 Recent Changes in the World Economy and the Global Financial Crisis 12
1.2.2 Recent Changes in World Energy Development 14
1.3 Energy Structural Changes in the G7 and BRICs. 18
1.4 Review of China's Energy Development 32
1.4.1 Rapid Economic Growth with a Lower Energy Consumption Growth Rate 32
1.4.2 Energy Supply Maintains a Rapid Growth Rate While the Energy Self-sufficiency Rate Has Declined 34

1.4.3 Less Carbon-Intensive and Cleaner Energy Structure and More Energy-Intensive Economic Structure . . . 37
1.4.4 CO_2 Emissions Grow Rapidly and CO_2 Abatement Pressures Increase . . . 38
1.5 New Changes and Trends in China's Energy Development . . . 39
1.5.1 Reform of the Energy Management Mechanism Keeps Moving . . . 39
1.5.2 Energy Demand Growth Rate Decreased Due to the Business Cycle . . . 40
1.5.3 Energy Supply Diversification Is Accelerating . . . 41
1.5.4 Striking Advances in Energy Conservation Development . . . 42
1.5.5 China's Energy Flow Analysis in 2008 . . . 44
1.6 Challenges and Reactions of China's Energy Development . . . 47
1.6.1 Huge Energy Demand with Considerable Uncertainty . . . 47
1.6.2 Insufficient Per Capita Energy Resources, Especially High-Quality Ones . . . 47
1.6.3 New Challenges Facing Energy Development Due to Global Climate Change . . . 48
1.6.4 Global Climate Change Has Brought About New Energy Challenges . . . 48
1.6.5 An Important and Effective Way of Facing Challenges: Improving Energy Efficiency . . . 49
References . . . 50

2 Relationship Between Energy Efficiency and the Economic System: Measuring Energy Efficiency . . . 53
2.1 Reconsideration of Energy Efficiency and Its Relation to the Economic System . . . 54
2.1.1 Understanding Energy Efficiency . . . 54
2.1.2 Measuring Energy Efficiency . . . 55
2.1.3 Energy Efficiency and the Economic System . . . 57
2.1.4 Energy Efficiency and Energy Conservation . . . 63
2.2 Indicators and Measurement of Energy Efficiency . . . 64
2.2.1 Energy Macro-efficiency . . . 65
2.2.2 Energy Physical Efficiency . . . 67
2.2.3 Energy Thermodynamics Efficiency . . . 68
2.2.4 Energy Value Efficiency . . . 69
2.2.5 Energy Allocation Efficiency . . . 70
2.2.6 Energy Utilization Efficiency . . . 74
2.2.7 Energy Economic Efficiency . . . 76
2.3 Summary . . . 78
References . . . 80

3 Impact of Economic Structural Changes on Energy Macro-efficiency 81
3.1 Linkages of the Industrial Structure and Energy Intensity 82
3.1.1 Statistical Description of the Change in Energy Intensity 82
3.1.2 Impacts of Internal Industrial Structural Change on Energy Intensity 86
3.1.3 Further Discussion of the Decomposition Method 96
3.2 Final Demand Structure and Energy Efficiency 97
3.2.1 Marginal Energy Consumption of Different Final Demands 97
3.2.2 Study on the Expenditure Elasticity of Residual Energy Consumption 103
3.2.3 Analysis of the Elasticity of Energy Macro-efficiency to the Investment Ratio 105
3.2.4 Analysis of the Direct and Embodied Energy Exports 107
3.3 Impact of the National Income Distribution Structure on Energy Demand 108
3.3.1 Analysis of the Income Elasticity of Household Energy Demand 108
3.3.2 Changes in the Income Distribution Pattern and Its Impact on Energy Consumption 110
3.4 Research Methodology of the Influence of Urbanization on Energy Demand with Supporting Evidence 112
3.4.1 Research into Urbanization and Household Direct Energy Consumption Based on the Divisia Decomposition Method 112
3.4.2 Research into Urbanization and Household Indirect Energy Consumption Based on the Input–Output Analysis Method 114
3.4.3 Research into the Construction Industry and Energy Demand Based on the Input–Output Analysis Method 115
3.5 Conclusion 115
References 116

4 Residential Energy Consumption 119
4.1 Residential Energy Consumption Characteristics in Some Representative Countries 120
4.1.1 Final Energy Consumption Structure by Sector in Some Representative Countries 120
4.1.2 Analysis of Trends in Residential Energy Final Demand for Some Representative Countries 122

4.1.3 Comparison of the Energy Consumption Structure Among Representative Countries. 124
4.1.4 Regional Comparison of Residential Energy Consumption 127
4.2 State of China's Residential Energy Consumption 127
4.2.1 Change in Residential Energy Consumption 128
4.2.2 Analysis of Different Kinds of Energy Consumption 130
4.2.3 Characteristics of the Residential Energy Consumption 133
4.3 Comparison Between Urban and Rural Residential Energy Consumption. 133
4.3.1 Differences Between Urban and Rural Residential Energy Consumption 134
4.3.2 Differences Between the Structure of Urban and Rural Residential Energy Consumption 137
4.4 Regional Comparison of Residential Energy Consumption. 140
4.4.1 Regional Comparison of Residential Energy Consumption 141
4.4.2 Regional Comparison of the Structures of Residential Energy Consumption 144
4.4.3 Impact Factors of Residential Energy Consumption: Examples from Three Regions 148
4.4.4 Characteristics of Regional Residential Energy Consumption 151
4.5 Impact Analysis of Urban Residential Energy Consumption. . . . 152
4.5.1 Impact Factors of Urban Residential Energy Consumption 153
4.5.2 Accounting Methodology and Data Description 155
4.5.3 Results Analysis and Discussion 159
4.5.4 Conclusions. 162
4.6 Summary 162
References. 164

5 Energy Efficiency in Key Sectors 167
5.1 Transportation Sector 168
5.1.1 Energy Consumption Characteristics in China's Transportation Sector. 168
5.1.2 Systematic Analysis of the Impact of Energy Intensity on Transportation 180
5.1.3 International Comparison of Energy Consumption in Transportation 184
5.1.4 International Comparison of Energy Consumption and Emission Reductions. 199
5.1.5 Summary 202

5.2 Energy Consumption in Buildings 204
5.2.1 Definition of Energy Consumption in China's Public Buildings 205
5.2.2 Development Tendencies and the Energy Consumption Situation of China's Public Buildings . . . 207
5.2.3 Characteristics of Energy Consumption in Large Public Buildings 212
5.2.4 Geographical Differences of Energy Consumption Among Large Public Buildings 214
5.2.5 Overall Features of Energy Consumption in Public Building 216
5.3 Energy Efficiency in the Electric Power Sector. 217
5.3.1 Energy Efficiency of Electric Power Generation 217
5.3.2 Energy Efficiency of Power Transportation and Distribution. 223
5.3.3 Electricity Allocation Optimization and Economical Transmission 224
5.3.4 Demand Side Management and Energy Efficiency 228
5.4 Summary 229
References. 230

6 Empirical Research About the Effects of Price on Oil Demand 233
6.1 Introduction 233
6.2 Research Method on the Demand Elasticity of China's Crude Oil 235
6.2.1 Variable Selections and Research Methods 235
6.2.2 Data Sources and Processing. 237
6.2.3 Data Analysis and Bounds Test. 238
6.3 Analysis of the Demand Elasticity of China's Crude Oil 240
6.3.1 Analysis of Crude Oil Demand Elasticity in the Long Run 240
6.3.2 Analysis of Crude Oil Demand Elasticity in the Short Run 242
6.4 Conclusions and Implications 245
References. 247

7 China's Regional Energy Efficiency 249
7.1 Decomposition Study of Regional Energy Macro Efficiency . . . 250
7.1.1 Theil Index Decomposition Method 250
7.1.2 Data Sources and Processing. 251
7.1.3 Results and Discussion 252
7.1.4 Econometric Analysis of Differences in Regional Energy Macro Efficiency. 254

7.2 Comparison of Regional Energy Utilization Efficiencies 258
7.2.1 Data Sources and Processing 258
7.2.2 Results and Discussion 259
7.2.3 Econometric Analysis of the Regional Energy Utilization Efficiency Differences 263
7.3 Evolution of Energy Physical Efficiency in the Regional Iron and Steel Sector 265
7.3.1 Introduction 265
7.3.2 Malmquist Index Decomposition Method 267
7.3.3 Data Sources, Results, and Discussion 272
7.4 Summary 274
References 275

8 Energy Efficiency in Developed Countries and Its Implications for China 277
8.1 International Comparison of Legal Mechanisms 277
8.1.1 Laws and Regulations 278
8.1.2 Energy Conservation Mechanisms 279
8.2 International Comparison of Fiscal Policy 281
8.2.1 Japan 281
8.2.2 United States 283
8.2.3 European Union 285
8.3 International Comparison of R&D Policy 286
8.3.1 Japan 287
8.3.2 United States 287
8.3.3 European Union 288
8.4 Other Policies to Promote Energy Efficiency 289
8.4.1 Japan 289
8.4.2 United States 290
8.4.3 European Union 290
8.5 Implications 291
References 297

9 Energy Saving Potential from End-Use Efficiency Improvements and Its Socioeconomic Impacts 299
9.1 Energy Efficiency and Rebound Effects 299
9.2 Analytical Tool: China's Energy and Environmental Policy Analysis Model 302
9.2.1 Computable General Equilibrium Model 302
9.2.2 China's CEEPA Model 303
9.3 End-Use Efficiency Analysis Without Additional Energy and Environmental Policies 306
9.4 Effects of Alternative Energy/Environmental Policies 312
9.4.1 Policy Scenarios 312
9.4.2 Results and Analysis 313

9.5 Discussion of Policies on Energy Efficiency Improvement 315
9.6 Summary 316
References 317

10 Prospects of China's Energy Efficiency 319
10.1 Historic Opportunities for China's Energy Efficiency Improvement 320
10.1.1 Solid Foundation for Energy Conservation Provided by Sustainable and Steady Economic Growth 320
10.1.2 Potential and Capacity to Realize Lower Energy Consumption Per Capita and Per Unit of GDP 321
10.1.3 Numerous Areas for Energy Conservation Provided by Low Energy-Intensive Industries 325
10.1.4 New Energy Conservation Opportunities Brought About by Industrial Structure Upgrading and International Technology Transfers Induced by Economic Globalization 328
10.1.5 Broader Markets Facilitate Advanced Energy Conservation Technology 328
10.1.6 Energy Conservation Laws and Market Mechanisms Lead to Energy Efficiency Improvement 330
10.1.7 Properly Upgrading the Residential Consumption Structure Can Reduce Energy Consumption Growth Rate 331
10.2 Prospects of Energy Efficiency in Developed Countries and in China 332
10.2.1 Potential for Realizing Lower Energy Consumption Per Capita in China 332
10.2.2 Possibility of Realizing Lower Energy Consumption Per Unit of GDP in China 333
10.2.3 Potential for Gaining a Faster Decline of Energy Macro-efficiency 334
10.2.4 China's Energy Macro-efficiency Prospects 334
10.3 Paths Leading to China's Low-Carbon Development 336
References 339

Abbreviations

CAAC	Civil Aviation Administration of China
CAAC-DPD	Department of Planning and Development, CAAC
CATS	China Academy of Transportation Sciences, MOT
CCYP	China Communications Yearbook Press
CEC	China Electricity Council
CGE	Computational General Equilibrium Modeling
CNMI	China Nonferrous Metals Industry Association
DEA	Data Envelopment Analysis
DEA-SBM	Slacks-Based Measure of Efficiency
DOT	Department of Transport, USA
EU	European Union
FNEC	The First National Economic Census
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GRP	Gross Regional Product
GWEC	Global Wind Energy Council
GWP	Gross World Product
ICP	International Comparison Program
IEA	International Energy Agency
IEEJ	Institute of Energy Economy of Japan
MER	Market Exchange Rate
MIC	Ministry of International Affairs and Communications
MOC	Ministry of Communications
MOR	Ministry of Railway
MOR-SC	Statistics Center, MOR
MOT	Ministry of Transport
MOT-DCP	Department of Comprehensive Planning, MOT
MOT-DPL	Department of Policy and Legislation, MOT
MPS	Material Product Balances
NBS	National Bureau of Statistics

NBS-DCS	Department of Comprehensive Statistics, NBS
NBS-DE	Department of Energy, NBS
NBS-DITS	Department of Industry and Transport Statistics, NBS
NBS-DNA	Department of National Accounts, NBS
NDRC	National Development and Reform Commission
NDRC-BE	Bureau of Energy, NDRC
NDRC-CTRI	Comprehensive Transportation Research Institute, NDRC
NDRC-ERI	Energy Research Institute, NDRC
NEN	Energy Terms of Subcommittee of National Comminute for Energy Science and Administration Standardization
OECD	Organization for Economic Co-operation and Development
ONELG	Office of the National Energy Leading Group
ORNL	Oak Ridge National Laboratory
PPP	Purchasing Power Parity
RD&D	Research, Development and Demonstration
SNA	System of National Accounts
SNEC	The Second National Economic Census
UK-DT	Department for Transport, UK
UN	United Nations
WEC	World Energy Council
WTO	World Trade Organization

Chapter 1
Energy Development in the World and China

Financial crises, energy prices, climate change, and low carbon economies were among the hot topics of world development in the past several years. The outbreak of the financial crisis in late 2008 took a heavy toll on the world's economy and resulted in the most serious recession since World War II. The UN Climate Change Conference held in Copenhagen in December 2009 resulted in the Copenhagen Accord, a political agreement struck by world leaders. The year 2010 was the last year for the Chinese government to achieve its targets for energy savings related to the "Eleventh Five-Year Plan" and it was also the first year in the Chinese government's struggle to cut carbon dioxide emissions per unit of GDP by 40–50 % by 2020. At present, all levels of the Chinese government are developing the "Twelfth Five-Year Plan," in which the topics relevant to energy resources and climate change will have a more important place. Under the aforementioned situation, this chapter aims to answer the following questions:

- What are the basic statistical characteristics of global economic development and energy supply and demand?
- Are there any notable improvements in the lopsided distribution pattern of world energy consumption?
- What are the characteristics of the evolving energy consumption structure in the major countries?
- What have been the new trends in the worldwide economy and energy development since 2008?
- What are the basic characteristics of economic development and energy supply and demand in China?
- What progress in energy savings was made in the "Eleventh Five Year Plan?"
- What are the challenges faced by China in terms of energy development?
- How should China cope with these challenges?

Y.-M. Wei and H. Liao, *Energy Economics: Energy Efficiency in China*,
DOI 10.1007/978-3-319-44631-8_1

1.1 World Energy Development Review

1.1.1 World Economy and Energy Consumption Are Significantly Correlated When Taking a Statistical Perspective

Energy resources are important in terms of both production and living standards; thus, energy consumption is always closely related to economic development. Ever since the industrial revolution, both economic development and energy consumption have experienced a relatively fast-increasing trend worldwide. The statistical data show that the gross world product (GWP) and gross energy consumption are positively related (Fig. 1.1). According to BP (2010), the World Bank (2010a, b), and our own analysis of the period from 1980 to 2009, the correlation coefficient between the two variables was 0.995; GWP increased from 17.8 to 39.4 trillion USD (at constant prices), an annual growth rate of 2.8 %; per capita GWP increased from 4000 to 5800 USD, an annual growth rate of 1.3 %; worldwide energy consumption increased from 6.6 billion tonnes of oil equivalent (toe) to 11.2 billion toe, an annual growth rate of 1.8 %; energy consumption per unit of GWP decreased from 3.73 to 2.84 toe/10^4 USD, a decrease of 23 %; and energy consumption per capita increased from 1.49 to 1.65 toe, an increase of 11 %. In general, while the world economy grew by 1 %, world energy demand increased by 0.64 % (Fig. 1.1).

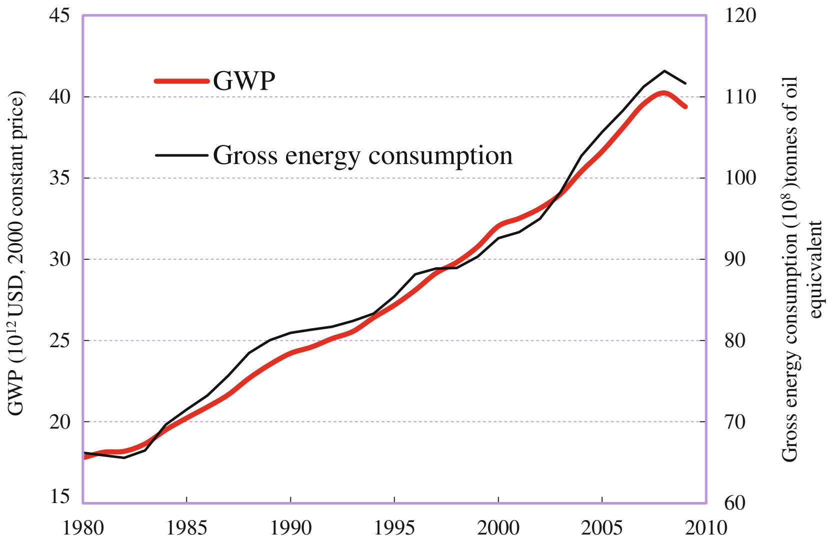

Fig. 1.1 Relationship between gross world production (*GWP*) and gross energy consumption (1980–2009). *Data sources* BP (2010), World Bank (2010b) and authors' calculations

Energy consumption in the OECD countries makes up a large percentage of the worldwide gross energy consumption, but it shows a decreasing trend. Energy consumption in the OECD countries in 1965 was 2.62 billion standard toe, which was 68.7 % of world aggregate consumption while energy consumption in 2009 was 5.22 billion standard toe, or 46.7 % of world aggregate consumption. The reasons are that (1) most OECD countries have turned into (or are already) industrialized countries, and they are steering towards low-energy industries and (2) some major developing countries have developed quickly, resulting in a sharper increase in their energy consumption while the OECD countries have been developing at a lower growth rate, resulting in a slower increase in their energy consumption.

The United States is the most developed country in the world, and it is also the country with the largest energy consumption. According to the data released by BP (2010), energy consumption in the United States was 2.18 billion standard toe or 19.5 % of world aggregate consumption. Among all energy sources, petroleum consumption was 0.84 billion tons (21.7 %), coal consumption was 0.50 billion tons (15.22 %) and natural gas consumption was 590 billion kiloliters (22.2 %).

Energy demand may experience a fast increasing trend in the future. According to the base scenario of the IEA (2009c), gross energy consumption worldwide could reach 16.8 billion standard toe in 2030, an average annual growth rate of 1.5 % from 2007 to 2030. Among all energy sources, petroleum demand would increase by 1.9 %, coal demand by 0.9 %, and natural gas by 1.5 or 35.6 %, 19.2 and 22.0 % of aggregate growth rate, respectively. According to the forecast, energy consumption in the OECD countries would increase slowly, with an annual growth rate of 0.2 % while the growth rate in the developing countries would reach 2.3 %. Growth in China and India would amount to 53 % of worldwide growth.

To satisfy energy demand and ensure energy supplies, investment in energy resources would keep increasing in the future. According to the IEA (2009c), the cumulative investment in the energy industry worldwide from 2008 to 2030 would reach 2.6 billion USD, approximately 1.4 % of the gross world product, where investment in the electricity industry would represent 53 % of total investment.

1.1.2 Different Energy Demand Elasticities of GDP in Different Development Stages

The relationship between energy consumption and economic development is significantly positive; in contrast, the aggregate economic elasticity of demand for energy has shown an ever-changing trend in past decades. Table 1.1 outlines the energy elasticity in different periods, including the first oil crisis, the second oil crisis, the Gulf War, and the “9/11” attacks as the cut-off points. Before the beginning of the first oil crisis, the energy elasticity was greater than 1.0, which was mostly caused by the fast-increasing demand for energy resources during the

Table 1.1 Aggregate economic elasticity of demand for energy at different periods (1965–2009)

Period	1965–1973	1973–1979	1979–1991	1991–2001	2001–2009
Elasticity of economic aggregate to energy demand	1.00	0.87	0.68	0.51	0.89
Economic annual growth rate in the developed countries	5.2	3.0	2.9	2.4	1.8
Economic annual growth rate in the developing countries	6.0	4.9	3.3	3.8	6.0

post-war reconstruction and industrialization. After the oil crisis, the developed countries had almost completed the industrialization process. They paid more attention to energy-saving and energy-efficiency improvements; thus, their demand for energy resources increased slowly.

In the late 20th century, the aggregate economic elasticity of demand for energy showed a decreasing trend. The major reason was that the economic growth rate in the developing countries was only slightly higher (1–2 %) than that in the developed countries in the last 50 years of the century. From the composition of world energy demand, we can see that the low growth rate in the developed countries somewhat softened the high growth rate in the developing countries, lowering the growth rate of world energy demand and reducing the energy elasticity. Since 2001, the sharp economic growth in the developing countries (almost 4 % higher than that in the developed countries) has driven the rapid increase in energy demand, which could not be completely offset by the lower growth rate of energy demand in the developed countries. Thus, the energy elasticity of demand showed an upward trend during this period (Table 1.1).

1.1.3 Different Decreasing Rates of Energy Intensity Across Countries

With economic restructuring and technological progress, most countries and regions in the world have shown a decreasing trend in energy consumption per unit of GDP since 1980 while some other countries have shown an increasing trend periodically. From 1980 to 2008, energy consumption per unit of GDP in the United States decreased by 44 % and that in Japan decreased by 23 %. For the developing countries, India decreased by 19 % and China decreased by 66 % (Fig. 1.2). The sharp decrease in China played a positive role in relieving global energy demand and greenhouse gas (GHG) emissions. The energy consumption per unit of GDP in South Africa and Brazil showed an increasing trend from 1980 to

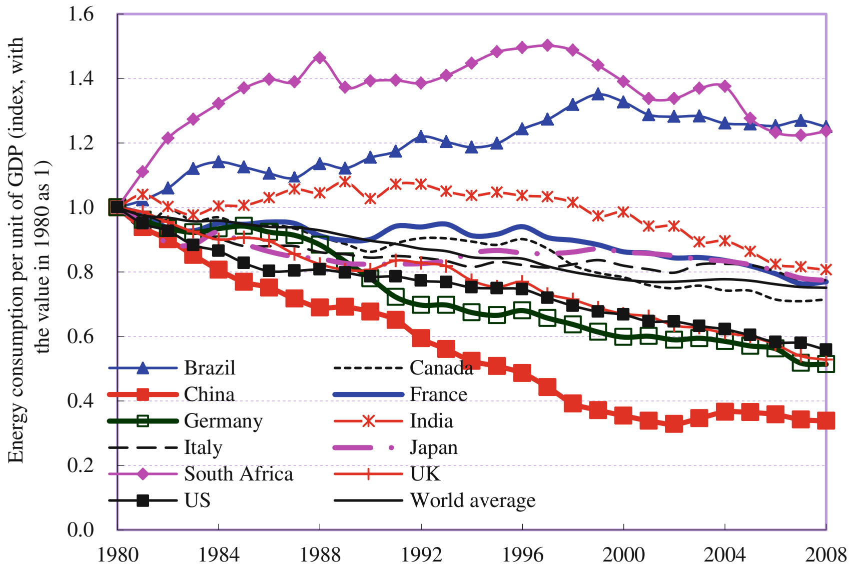

Fig. 1.2 Energy consumption per unit of GDP (index) in major countries (1980–2008). *Data sources* BP (2009), World Bank (2009) and authors' calculations

2000 before slowing down after 2000. Some major developing countries have great potential in reducing their energy consumption, improving their technologies and shifting to less energy-intensive industries in the near future. To realize these objectives, more specific and enforceable strategic planning is needed.

1.1.4 There Is no Significant Improvement in the World's Unbalanced Energy Consumption

Similar to global economic development, the energy consumption in different countries varies greatly (Fig. 1.3). The annual per capita energy consumption in the developed and OPEC countries was ranging from 3 to 10 toe and that in the State of Qatar exceeded 20 toe. According to the World Bank (2010b), the per capita energy consumption in most developing countries lags far behind than that in developed countries. For example, the per capita energy consumption in the United States is more than four times the world average. It is worth noting that the residential energy demand in most developing countries is still for basic living needs while that in the developed countries is for luxury or enjoyment. Similar to global energy consumption, the energy consumption within a country also differs greatly among regions, social classes, and income groups.

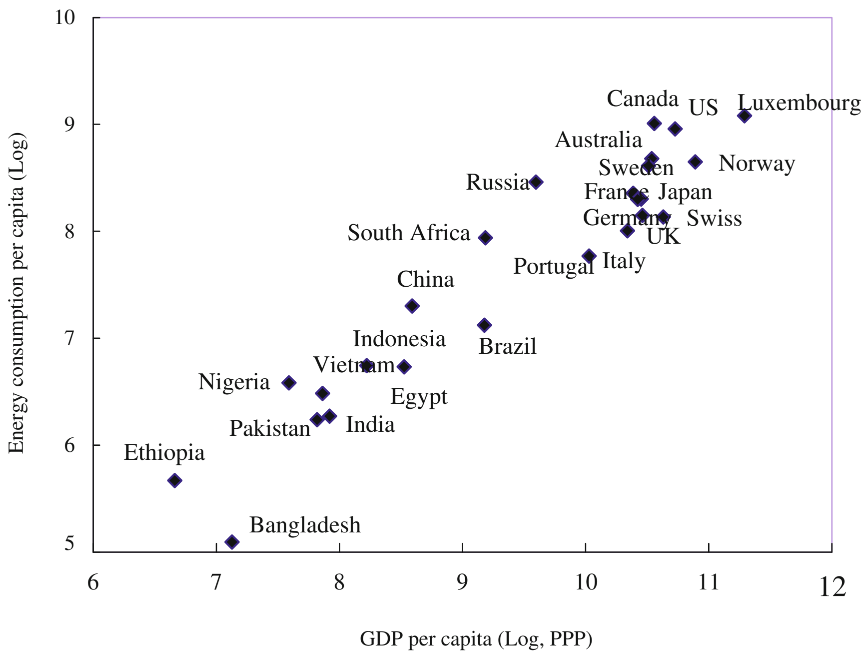

Fig. 1.3 Per capita energy consumption in major countries (2007). *Data source* World Bank (2010b)

1.1.5 *Energy Poverty and the Induced Health Issues Are Still Serious*

According to IEA (2009d), there are 2.5 billion people in the world who are still using traditional bio-energy and biomass to produce electricity for daily life and 1.5 billion people have no access to electricity services. The data from WTO (IEA 2009c) showed that 1.5 million people die from indoor air pollution every year because of their use of solid fuels (85 % of which is traditional bio-energy and biomass) and coal (15 %). If there are no new policies, electricity services will still be unavailable to 1.3 billion people in 2030. The data in the “2010 Millennium Development Goals” issued by the United Nations on June 23, 2010 (UN 2010) showed that more than 40 % of people in over 70 countries are still using solid fuels (Fig. 1.4).

1.1.6 *World Energy Trade Increases Steadily and Natural Gas Emerges Progressively*

Because the spatial distribution of energy resources and energy demand is unmatched, global energy trading has kept a quickly increasing trend since the

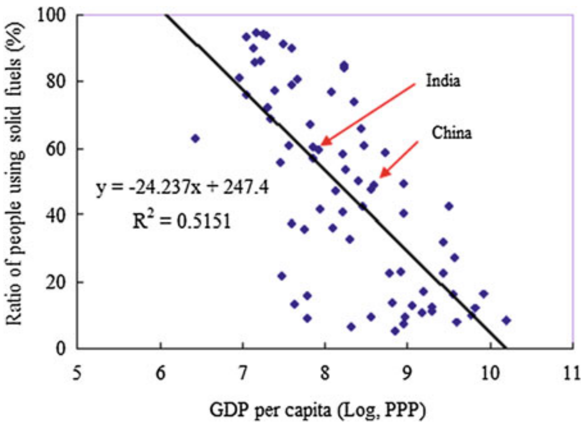

Fig. 1.4 Ratio of people using solid fuels in major countries (2007). *Data sources* World Bank (2010b) and UN {UN 2010#1135}. Includes data for the United States and another 76 countries (mostly developed countries and the oil-and-gas rich countries) where the ratio of people using solid fuels is less than 5 %. The data for Uganda and 19 other countries (mostly African countries) where the ratio is greater than 95 % are not included

1990s with the globalization and development of transport technology. World oil trade increased from 1.34 billion tons in 1990 to 2.54 billion tons in 2008, and the ratio of oil trade to oil consumption increased from 47 to 64 % (Table 1.2). Saudi Arabia and Russia are the world's leading crude oil producing and exporting

Table 1.2 World's top ten crude oil producers, net exports and imports

Country	Production (million tons, 2008)	Percentage of world total	Country	Net exports (million tons, 2007)	Country	Net imports (million tons, 2007)
Saudi Arabia	509	12.9	Saudi Arabia	339	United States	573
Russia	485	12.3	Russia	256	Japan	206
US	300	7.6	Iran	130	China	159
Iran	214	5.4	Nigeria	112	India	122
China	190	4.8	United Arab Emirates	105	Korea	118
Mexico	159	4	Norway	97	Germany	106
Canada	155	3.9	Mexico	89	Italy	94
Kuwait	145	3.7	Angola	83	France	81
Venezuela	137	3.5	Angola	82	Spain	59
United Arab Emirates	136	3.5	Iraq	81	Holland	58
Others	1511	38.4	Others	583	Others	515
World	3941	100	Total	1957	Total	2091

countries (approximately 25 % of the world's oil production and approximately 30 % of the world's net exports of oil). The United States, Japan, China, and India are the leading crude oil importing countries. The United States imported 0.57 billion tons of crude oil in 2007, 27.4 % of the world's total.

Natural gas plays an increasingly important role in global energy trading compared with crude oil resources, but the spatial distribution of natural gas resources is much more uneven. Natural gas reserves in Russia, the State of Qatar, and Iran amount to 56 % of the world's total. In the early stage of natural gas development, large-scale international/regional trading could not be achieved, and natural gas was generally consumed directly on site or transformed into electricity due to the limitations of storage and transportation technologies. Since the 1960s, international natural gas trading has grown. Before 1970, the leading natural gas importing country was the United States. With the outbreak of the first oil crisis, the crude oil supply in the developed countries was greatly challenged. To alleviate the energy shortage, some countries turned to importing natural gas as an important oil supplement. Since then, natural gas trading has attracted more and more attention from governments and enterprises and has played an increasing role in global energy trading.

With the development of storage and transportation technologies, there has been a swift expansion of natural gas pipelines, liquefied natural gas (LNG) carriers and receiving stations. Today, there are three natural gas trading markets based on European pipelines, Asia-Pacific LNG carriers and North American pipelines. In the early 1970s, natural gas trading accounted for only 5.5 % of total gas consumption, most of which was based on pipelines (only 6.2 % was LNG). In the past decades, however, natural gas trading has developed swiftly, especially LNG trading. By 2008, natural gas trading accounted for 29.7 % of total consumption, a quarter of which was LNG (Table 1.3).

The natural gas in Japan and Korea was mainly imported from southeastern Asia, Australia, and the Middle East and that in Europe was mainly imported from

Table 1.3 World's natural gas consumption and trading (1971–2008)

Year	1971	1990	2000	2006	2007	2008
Total natural gas consumption (10^2 million cubic meters)	11,000	20,721	25,280	29,338	30,632	31,542
Total natural gas trading (10^2 million cubic meters)	602	5352	6440	8808	9106	9373
Total LNG trading (10^2 million cubic meters)	40	740	1400	2159	2311	2256
Ratio of gas trading to gas consumption (%)	5.5	25.8	25.5	30.0	29.7	29.7
Ratio of LNG trading to gas consumption (%)	0.4	3.6	5.5	7.4	7.5	7.2
Ratio of LNG trading to gas trading (%)	6.6	13.8	21.7	24.5	25.4	24.1

Russia and North Africa. Since the 1980s, natural gas imports from both LNG carriers and pipelines have grown quickly in the OECD countries. Pipeline gas was mainly imported from the former Soviet Union and Eurasian countries/regions. LNG imports amounted to 30 % of total imports. With the development of gas storage and transportation technologies, natural gas trading will become part of the future global market. With the growing importance of LNG for satisfying natural gas demand, there are many countries and regions building or planning to build LNG import projects. Constructions of natural gas pipelines and LNG receiving stations are also developing very quickly, so natural gas imports are increasing dramatically.

At present, natural gas trading is centered in a few countries. According to BP (2010), Russia, Canada, and Norway are the world's leading export countries (natural gas exports in these three countries amounted to 58 % of the world's total in 2009) while the United States, Germany, and Italy are the leading gas pipeline import countries (gas pipeline imports in these three countries was approaching 40 % of world's total in 2009). The State of Qatar, Malaysia, and Indonesia are the leading LNG exporters (LNG exports in these countries amounted to 43 % of the world's total in 2009), and Japan, Korea, and Spain are the leading LNG importers (LNG imports in Japan were 85.9 billion cubic meters in 2009, 35 % of world's total imports[1] while LNG imports in Korea and Spain were 34.3 and 27.0 billion cubic meters, respectively). In the Asia-Pacific countries, China, India, and other emerging markets show great potential for natural gas imports.

Coal trading is primarily in hard coal, coking coal, and steam coal. The data from the IEA (2009a) and the results from our analysis show that global coal trading is growing fast in the 21st century, especially for hard coal and steam coal (Fig. 1.5). Transportation for coal trading is basically maritime transportation, which accounts for 90 % of total trading. Australia, Indonesia, and Russia are the world's leading coal export countries. China was also among the top coal exporters before 2006, but coal exports have decreased substantially since then because of growing domestic demand and the restrictions of resource-export policies, Data from Chinese Customs indicates that 2009 was the first year that China became a net importer of coal, importing 0.103 billion tons of coal that year. In terms of coking coal resources, China was a big exporting country for a long time in the past, when coking coal exports amounted to half of the world's total. Due to growing domestic demand and the resultant restriction in resource-export policies and the sluggish world coal demand, coking coal exports dropped substantially to 0.54 million tons in 2009.

[1]Since the Great East Japan Earthquake and tsunami caused a nuclear accident on March 11, 2011, Japan has ceased to generate electricity from most of its nuclear reactors. To meet the electricity supply gap, Japan increased its electricity generation from oil and gas, which resulted in significant LNG imports in 2011 and 2012.

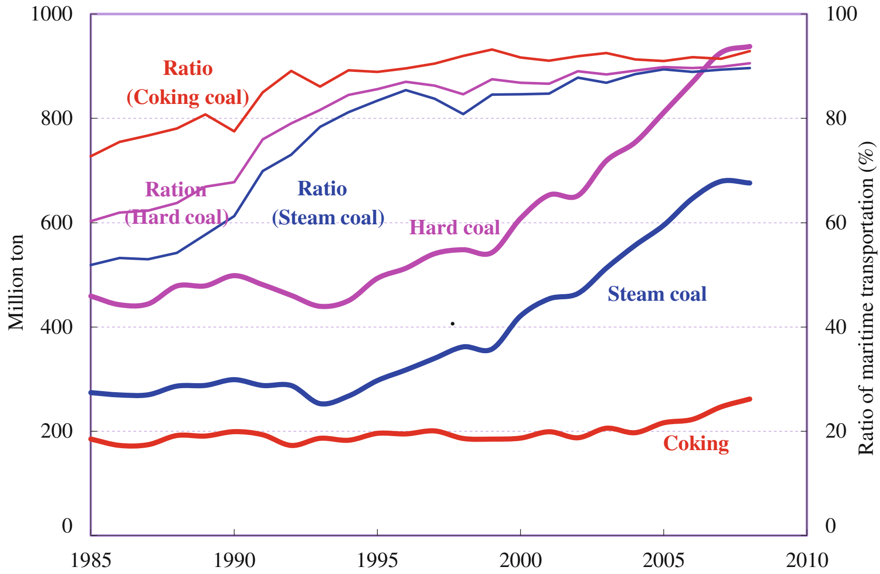

Fig. 1.5 World's coal trading and ratio of maritime transportation (1985–2010) IEA (2009b)

1.1.7 Fossil Fuel-Based Energy Consumption Has Caused Serious Pollution Are Carbon Emissions

While the volume of energy consumption was increasing rapidly, the structure of consumption was also changing continuously, motivated by the reserves of energy resources and the limitation of technologies. During the first industrial revolution, the ratio of coal to total energy consumption increased sharply and thus, the coal mining/consumption areas were always the world's industrial centers. But now the major primary energies worldwide include fossil fuels, such as oil, coal, and gas, even though different countries/regions have different structures due to different resource endowments. The IEA (2009b) suggests that the total energy consumption was 12 billion standard toe in 2007, with the ratio of coal at 26.5 %, oil at 34.0 % (a drop of 12.2 % compared with that in 1973), gas at 20.9 % (a rise of 4.9 %), nuclear energy at 5.9 % (a rise of 5.0 %), hydroelectricity at 2.2 %, bio-energy and waste at 9.8 %, and others at 0.7 % (Fig. 1.6). According to its base scenario prediction, the proportion of the different energies in 2030 will be coal at 29.1 %, oil at 29.8 %, gas at 21.2 %, nuclear energy at 5.7 %, hydroelectricity at 2.4 %, bio-energy and waste at 9.6 %, and others at 2.2 %.

The over-exploitation and combustion of fossil fuels to meet the energy needs are posing serious threats to the environment and contributing to environmental pollution, ecological damage, and global warming. According to IEA (2009a), there were 29 billion tons of carbon dioxide emissions from fossil fuels, 42.2 % of which was from coal, 37.6 % from oil, and 19.8 % from natural gas (Fig. 1.7). The

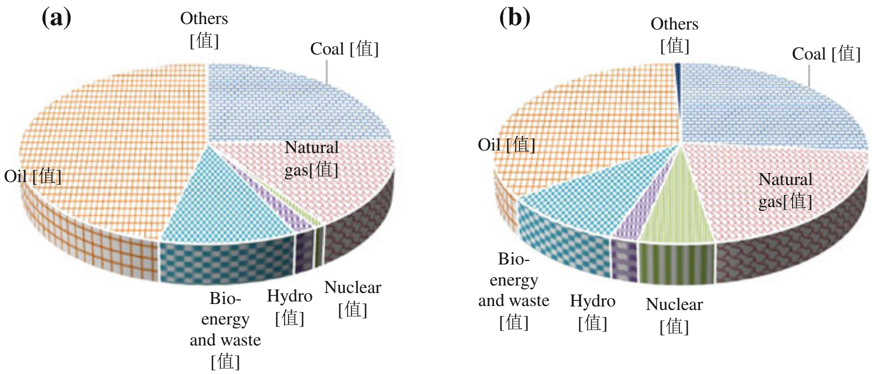

Fig. 1.6 **a** World energy consumption structure in 1973, **b** world energy consumption structure in 2007. *Data source* IEA (2009c)

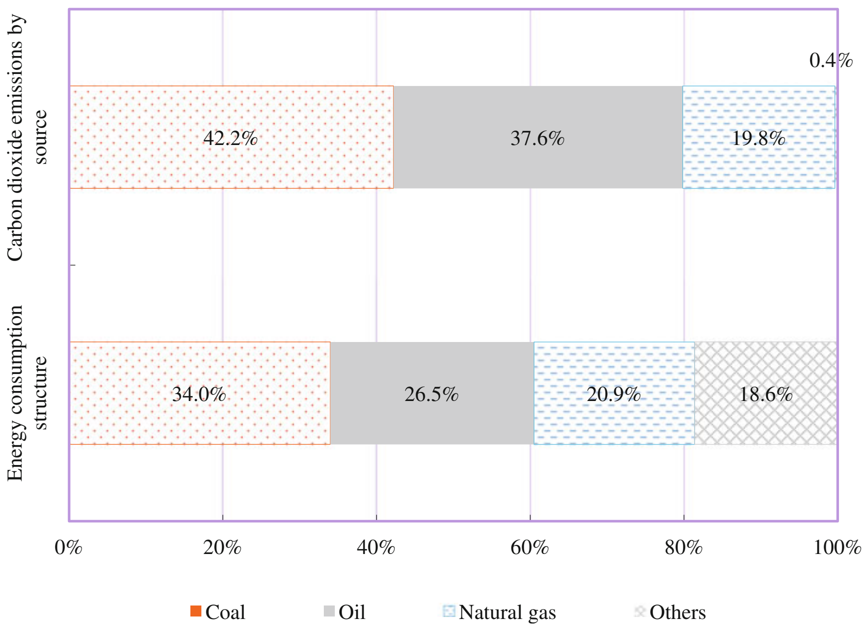

Fig. 1.7 World's energy consumption structure and carbon dioxide emissions. *Data source* IEA (2009a). Only carbon dioxide emissions from fossil fuel combustion were considered

leading carbon dioxide emission countries were China, the United States, Russia, India, and Japan, and the emissions from these countries accounted for 55 % of the world's total. The electricity sector at 41 % contributed the most to carbon dioxide emissions, followed by transportation sector at 23 %. The underlying reason was that the carbon dioxide emission factors for coal and oil were the highest, and coal was mostly used in the electricity sector while oil was mostly used in the transportation sector.

1.2 New Trends of World Energy Development from 2008 to 2010

1.2.1 Recent Changes in the World Economy and the Global Financial Crisis

In recent years, the modern financial system has become more vulnerable and fragile as a result of complex financial securities, a dependence on short-term funding markets, international trade imbalances, and high corporate and consumer debt levels. Any shock or stimulus, such as the ongoing foreclosure crisis, the failure of key financial institutions, regulatory and market-based controls, or unhealthy stock and housing markets, could disrupt the delicate equilibrium of the system.

Since late 2008, the subprime mortgage crisis in the United States has spread worldwide. Both developed and developing countries have been adversely affected by the crisis. According to the World Bank (2010a), the world's economic growth rate in 2008 was 1.7 %, a drop of 2.2 % from the previous year, and the growth rate in 2009 was −2.2 %, the lowest since World War II, when growth in the developed countries was −3.3 % and that in the developing countries was 1.2 % (−2.2 % excluding China and India). Global trade decreased by 14.4 % in 2009 and the prices of the major commodities dropped substantially as well. The United States, Japan, European Union, and other developed countries suffered greatly during this crisis (Table 1.4).

Even though the crisis represented the most serious recession after World War II, the economic systems have been restored and even reinforced since late 2009, which is much earlier than expected due to the efforts of all governments, including the measures of government collaborations, the global economy is recovering and maintaining fast and stable growth. Despite the uncertainty, such as the high unemployment rate in the major economies and a serious debt crisis in a few countries, the global economy in 2010 was better than expected. Therefore, many international organizations have raised their economic growth rate expectations for the major economies since late 2009.

The global economic recession and the subsequent quick recovery have brought a great fluctuation in the world's energy prices (Fig. 1.8). The crude oil price for delivery in the New York Commodity Exchange dropped from a record high of 15 USD/barrel on June 3, 2008 to 34 USD/barrel (a drop of 77 %) on December 19, 2008. After March 2009, oil prices started to slowly rise. Generally speaking, the change in oil prices is a quarter earlier than the change in oil developments at the microeconomic level.

Table 1.4 World's economic situation, including estimations and forecasts (2008–2012) (%)

	2008	2009e	2010f	2011f	2012f
Real GDP growth rate					
World	1.7	−2.1	3.3	3.3	3.5
European Union	0.4	−4.1	0.7	1.3	1.8
Japan	−1.2	−5.2	2.5	2.1	2.2
US	0.4	−2.4	3.3	2.9	3
Developing countries	5.7	1.7	6.2	6.0	6.0
China	9.6	9.1	9.5	8.5	8.2
Russia	5.6	−7.9	4.5	4.8	4.7
Brazil	5.1	−0.2	6.4	4.5	4.1
India	5.1	7.7	8.2	8.7	8.2
South Africa	3.7	−1.8	3.1	3.4	3.9
World's trading growth rate	3.2	−11.6	11.2	6.8	7.2
Growth rate of bulk commodities price (oil excluded)	0.0	−21.6	16.8	−4.0	−5.4
Growth rate of oil price	36.4	−36.3	26.4	−4.5	−0.9

e estimation, *f* forecast

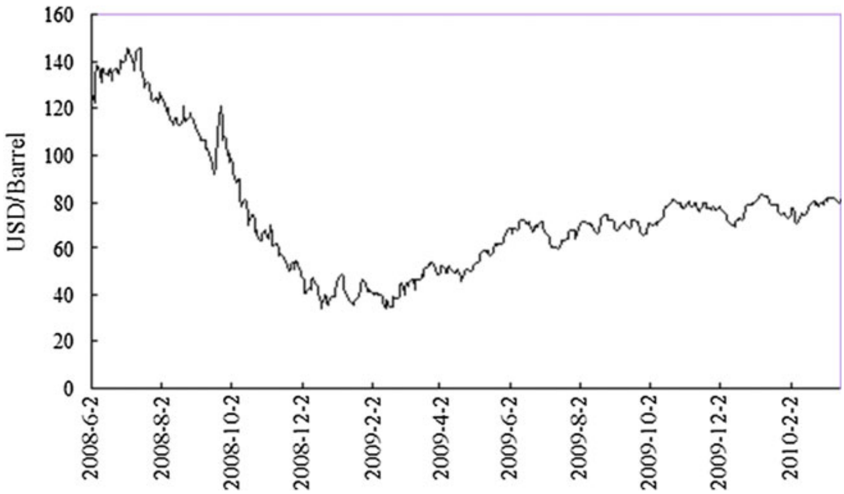

Fig. 1.8 World crude oil prices (June 2008–April 2010). *Data source* IEA (2010)

The financial crisis had a great adverse impact on the world economy and it could bring about far-reaching impacts on the world's growth rate and economic structure, and the direction of technical innovations. But the importance of financial products in global long-term economic development cannot be denied. Many countries have reinforced or improved their financial regulations, but the pace of financial product development will not slow down, and the financial markets and financial products related to reducing carbon dioxide emissions will keep growing as well.

In December 2009, the UN Climate Change Conference was held in Copenhagen, Denmark. Although appealing in terms of its goals, since the participating countries had greatly different ideas about carbon emissions, only the "Copenhagen Accord" without legally binding force was achieved. The Chinese government declared its intention to cut down its carbon dioxide emissions per unit of GDP by 40–50 % by 2020, which would be incorporated into the medium- and long-term plans within its National Economic and Social Development programs. As a developing country in the process of industrialization and urbanization, China needs an enormous effort to achieve this target. The UN subsequently held another Climate Change Conference in Cancun, Mexico, on November 29, 2010.

1.2.2 Recent Changes in World Energy Development

Triggered by the world economy recession, global energy demand slumped substantially in 2009. According to BP (2010), global energy demand decreased by 1.1 % in 2009. The IEA (2010b) showed that global oil demand was 84.94 million barrels per day (bbl/d) in 2009, a decrease of 1.5 % from the previous year (Fig. 1.8). Oil demand in the OECD countries was 45.49 million bbl/d, a decrease of 4.4 %, while that in China was 7.89 million bbl/d, an increase of 7.7 %, and that in other countries was 30.77 million bbl/d, an increase of 0.6 %. The second quarter of 2009 was the slowest period in recent years in terms of energy demand, with a daily demand of 84.1 million barrels. The expected global oil demand was 86.5 million bbl/d in 2010, with a growth rate of 1.8 % from the previous year. The global electricity consumption decreased by 1.6 % in 2009, the first negative growth rate since World War II (Fig. 1.9).

Global energy investment fell significantly. According to the estimations by IEA (2009c), global investment in primary oil and gas production decreased by approximately 90 billion USD, with a decrease of 19 %. More than 20 plans for large-scale oil and gas projects (with a daily oil production capacity of approximately 2 million barrels) were cancelled or suspended indefinitely and approximately 29 projects (with a daily oil productive capacity of about 38 thousand barrels) were postponed by at least 18 months. Global investment in bio-energy declined 18 % in 2009. Mergers and acquisitions in the global energy market were also affected by the crisis, but they quickly recovered. According to IHS Herold (2010), mergers and acquisitions of enterprises and assets in terms of primary oil and gas production declined 10.4 billion USD in 2008, a decrease of 50 %, before recovering to 14.5 billion USD in 2009, an increase of 40 %.

Affected by the global financial crisis, rising energy prices, over-exploitation of fossil-fuels, and difficulties in global climate change negotiations, many countries have attached great importance in technological innovations in the energy field. Even though investment in energy production is declining, many countries are

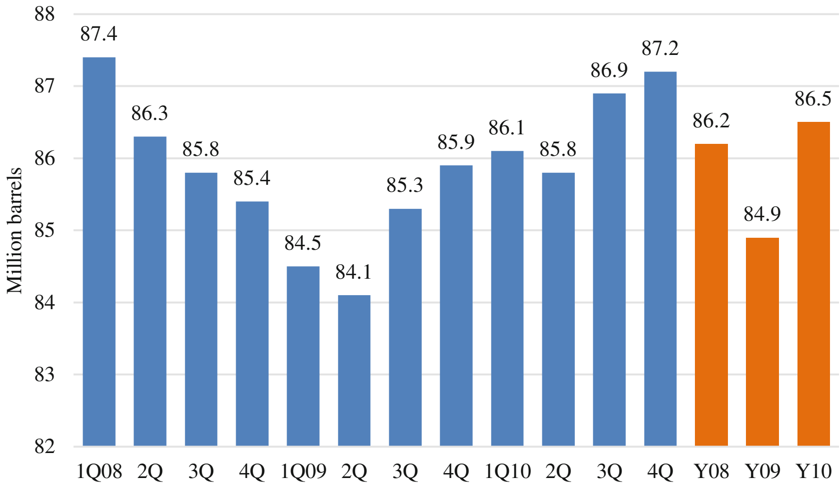

Fig. 1.9 World crude oil demand (2008–2010). *Data source* IEA (2010b). *Y* stands for year, *Q* stands for quarter

providing more support for energy technology research and development (R&D) to cope with the economic crisis and to boost economic growth (Table 1.5). The data from the IEA show that the government budgets for energy technology R&D and promotion in selected developed countries jumped to 29.4 billion USD in 2009, an increase of 113 % from the previous year.

In terms of renewable energy, wind power capacity increased 26,282 MW, or 32 %, in 2008, and 36,422 MW, or 43 %, in 2009 (Table 1.6), according to the Global Wind Energy Council (GWEC 2010). The data from REN21 (2010) show that wind power capacity has already surpassed small hydropower capacity (Tables 1.7 and 1.8). The data also indicate that world ethanol production in 2008 was 67 billion liters and biodiesel production was 12 billion liters. The United States and Brazil enjoyed an absolute advantage in ethanol production and made up

Table 1.5 Government budgets in energy technology R&D and extension for some developed countries

	Year 2008 (Million US$)	Year 2009 (Million US$)	Growth rate in 2009 (%)
Canada	561	706	25.9
Germany	563	659	17.1
Japan	3499	3286	−6.1
Norway	83	128	54.3
Swedish	103	138	33.5
UK	243	395	62.2
US	4442	19,329	335.2
IEA	13,772	29,382	113.3

Table 1.6 Wind energy installed capacity, including newly installed capacity, in 2009

Country	Installed capacity (MW)	Percentage of world total (%)	Country	Newly installed capacity (MW)	Percentage of world total (%)
US	35,159	22.3	China	13,000	34.7
Germany	25,777	16.3	US	9922	26.5
China	25,104	15.9	Spain	2459	6.6
Spain	19,149	12.1	Germany	1917	5.1
India	10,926	6.9	India	1271	3.4
Italy	4850	3.1	Italy	1114	3
France	4492	2.8	France	1088	2.9
UK	4051	2.6	UK	1077	2.9
Portugal	3535	2.2	Canada	950	2.5
Denmark	3465	2.2	Portugal	673	1.8
World	157,899	100	World	37,466	100

Table 1.7 Global renewable energy development (2006–2009)

Indicators of renewable energy development	2006	2007	2008
Investment in renewable energy (10^8 US$)	630	1040	1200
Renewable electric power installed capacity (large hydro power excluded, GW)	207	240	280
Renewable electric power installed capacity (large hydro power included, GW)	1020	1070	1140
Wind energy installed capacity (GW)	74	94	121
Solar energy installed capacity (GW)	5.1	7.5	13
Solar water heater capacity (GWth)	105	126	145
Fuel ethanol production (10^8 L)	390	500	670
Biodiesel production(10^8 L)	60	90	120

61 % of the world's total in 2008, with an annual production of 34 and 27 billion liters, respectively. The European Union led in terms of biodiesel production, with an annual production of 8 billion liters in 2008 or two-thirds of the world's total. Solar energy power generation in Germany and Spain has developed quickly, with an installed capacity of 54 and 33 GW, respectively, at the end of 2008, together representing 67.5 % of the world's total. The Chinese government is determined to develop non-fossil fuels and it plans to raise the proportion of non-fossil fuels in primary energy consumption to 15 % by 2020. The government has raised its target for renewable energy production several times, with the ultimate goal of a wind power-installed capacity of 1 billion MW and a solar power installed capacity of 200 million MW by 2020. Transportation is an important and intensive user of energy. An increasing number of automobile corporations are producing dynamic and electric vehicles, and more governments are using policy incentives to boost the sales of these new vehicles.

Table 1.8 Renewable energy productive capacity in major countries in 2008, (GW)

Indicator	World total	Developing country	EU 27	China	US	Germany	Spain	India	Japan
Wind power	121	24	65	12.2	25.2	23.9	16.8	9.6	1.9
Small hydro power	85	65	12	60	3.0	1.7	1.8	2.0	3.5
Biomass power	52	25	15	3.6	8.0	3.0	0.4	1.5	>0.1
Solar power	13	>0.1	9.5	>0.1	0.7	5.4	3.3	−0	2.0
Geothermal power	10	4.8	0.8	−0	3.0	0	0	0	0.5
Solar thermal power	0.5	0	0.1	0	0.4	0	0.1	0	0
Tidal power	0.3	0	0.3	0	0	0	0	0	0
Renewable energy power installed capacity (large hydro excluded)	280	119	96	76	40	34	22	13	8
Large hydro-power (GW)	860								
Total electricity installed capacity (GW)	4700								

Nuclear power, which is highly controversial, has also been developing very quickly. The Chinese government has set a target of 40 million kilowatts of nuclear installed capacity by 2020. According to the current growth rate, however, this target is expected to be reached five years earlier and the installed capacity will be 70 million kilowatts by 2020. There are 23 units of total 2.54×10^4 MW under construction in China, ranking the country number one in the world. The United States is also promoting the development of nuclear power, despite all interventions. A March 2010 draft of an energy development plan in Japan has attached great importance to low-carbon energy, especially nuclear power. The country plans to build 14 additional nuclear power stations and increase the consumption of nuclear power from the current 60 % of total energy use to 90 % by 2030.

There are many problems in the global energy supply system, especially relating to gas, oil, and electricity. On April 20, 2010, a massive explosion rocked the Gulf of Mexico Deepwater Horizon rig leased by BP, a British energy company. This was the most serious oil spill that has ever happened in the United States. One-fourth of the natural gas in the EU is supplied by Russia, 80 % of which is piped through Ukraine. Because of changes in the political situation in Ukraine, including the changing interests of Russia in Ukraine and the intervention of other countries, the gas prices and transit fees have been constantly in flux and greatly threaten the stable supply of natural gas in Europe. Moreover, the Somalia pirates have aggravated the crude oil transportation by sea and many countries have suffered from widespread electricity outages and power grid failures in recent years.

1.3 Energy Structural Changes in the G7 and BRICs

Since the Industrial Revolution, coal, oil, natural gas, hydropower, nuclear power, and renewable energy resources have been exploited and utilized on a large scale. The evolution of the energy use structure has promoted and reflected the trend of world economic development and social progress. Meanwhile, it has also greatly impacted global carbon dioxide emissions. Human-induced carbon dioxide emissions are mainly from fossil energy use.

The historical background, resource endowment, economic strength, and stage of development of the different countries vary substantially. The US, UK, France, Japan, Germany, Italy, and Canada are the member states of the former "Group of Seven" (G7) and they are major industrialized countries. The G7 countries play a significant role in the global economic, political, and energy fields, with 53 % of the world's total GDP (2008, rate method) and 34 % of the world's total energy consumption (2007). The historical experiences and lessons learned from energy development in the G7 countries provide plenty of useful references for the developing countries. China, India, Brazil, and Russia (generally called the "BRICs") are the most important developing countries as well as emerging market countries. These four countries are experiencing rapid growth and they not only have large economies, but they are also playing an increasingly important role in the international community. The combined GDP of these countries account for 14 % of the world's total (2008, rate method) and their energy consumption amounts to 29 % of the world's total (2007). In addition, their proportions of incremental economy and energy in the world's total incremental economy and energy are even higher.

Here, our analysis mainly focuses on the energy structure, historical changes, and evolution in the aforementioned 11 countries, especially the developed countries (Liao and Wei 2010). The original data were collected from the International Energy Association (IEA 2008), World Bank (2009), National Bureau of Statistics (NBS 2009), Global Wind Energy Council (GWEC 2009), and the Renewable Energy Policy Network for the 21st Century (REN21), as well as other agencies, and the data were cross-referenced using the thermal equivalent method (excluding the energy structure of electric power).

(1) The structure of the primary energy production in these countries is mainly subject to their resource endowment and technical and cost constraints and the development and use of fossil energy and hydropower have a high priority in most countries.
    China and India are abundant in coal reserves, so coal production is an important part of total energy production in these two countries, at 71 and 45 %, respectively (according to 2006 data, which applies throughout this paragraph). India is a country with a low urbanization level (29 %) and an

enormous rural population; thus, rural biomass energy occupies a large share of the total (37 %). Also, the US is abundant in coal and oil reserves. Coal production amounts to 40 % of total energy production, but due to policy restrictions, oil production is only 19 % of total energy production. Oil and natural gas resources in Russia are very rich, and their production takes up 82 % of the country's total energy production. In Germany, the fossil fuels are poor. However, coal has a relative advantage over oil and natural gas, and it makes up a large percentage (39 %) of Germany's energy production. Similar to Germany, oil and gas make up a large percentage of the total energy production in the UK and Italy.

France and Japan are extremely scarce in fossil fuels and their energy production is mainly from nuclear power (86 and 78 % of total energy production, respectively). Canada, Italy, Japan, and Brazil are rich in hydropower, which is cost-effective and environment-friendly. Therefore, hydropower production represents a relatively higher proportion of total energy production in these countries (Fig. 1.10). The geothermal resource in Italy is abundant and has been well exploited and utilized for a long time, thus playing an important role in the country's total energy production (18 % in 2006). In addition, the government in Brazil has many policies and has set up many institutions to encourage biomass energy development, so bio-energy represents a large percentage of energy production.

(2) The propulsion of the development stages, the discovery and advancement of large-scale oil and gas resources, the international geopolitical changes of the energy resources, and the national government policy preferences have greatly influenced the trend of changes in the energy production structure.

Energy demand has grown quickly in the developing countries, whose incremental energy production has mainly come from fossil fuels. As

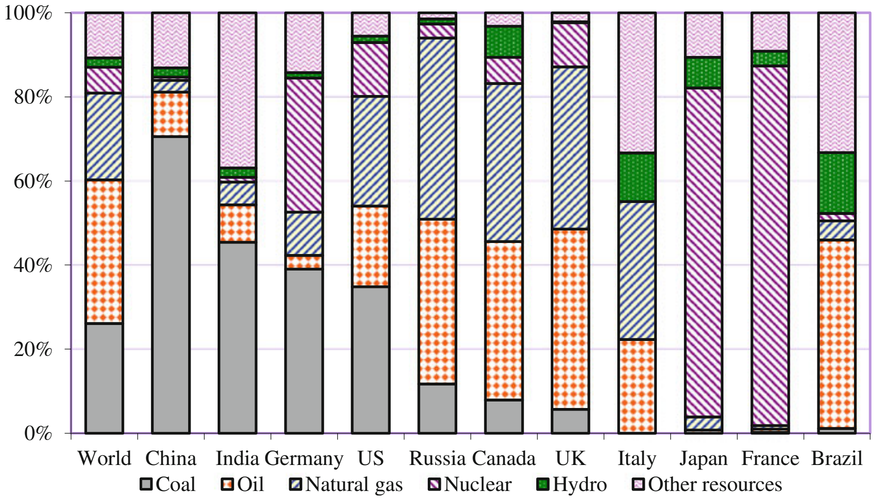

Fig. 1.10 Structure of energy production in some major countries in 2006. *Data sources* IEA (2008) and authors' calculations

examples of developing countries, China, India, and Brazil have large rural populations. In the past decades, however, they have experienced a period of rapid industrialization. With the decline in the rural population, improvement of rural living standards, and increasing availability of alternative energy, the ratio of biomass energy to total energy production has sharply decreased. With the advancement of industrialization and restrictions of energy resource endowment, the importance of coal resources has been growing in China and India while hydropower and petroleum resources have been growing in Brazil.

Energy production in the developed countries has been greatly influenced by government policy. As the largest developed country, the economic structure of the US has developed towards a low-energy orientation, thus slowing the growth of the country's total energy production. With the development and operation of the oil fields in the North Sea and the support of the government in 1975, there has been an upsurge in petroleum oil production in the UK, and total energy production had sharply increased. Moreover, the UK has recently changed from a net exporter, which continued for more than 20 years, into a net importer. Since the first world oil crisis in 1973, the US government has always encouraged alternatives to petroleum. Owing to the restriction of petroleum exploitation caused by resource and environmental protection policies, as well as safety policies, the proportion of petroleum oil production has continued to decline in the US. By 2008, the percentage had decreased to 18 %. In 1978, the US government enacted the "Power Plant and Industrial Fuel Use Act" to restrict the construction of power plants fueled by oil or natural gas and encouraged the use of coal and other alternative fuels. The ratio of coal production grew steadily from 1971 to 1990, before maintaining a 35 % proportion of total energy production thereafter. On the contrary, the ratio of natural gas production decreased slightly during the 1971–1986 period before increasing and then maintaining an approximate 27 % share of total energy production since 2000 (Fig. 1.11).

In response to the first world oil crisis, nuclear power in the developed countries developed rapidly in the 1970s. However, the nuclear power accident at Three Mile Island, Pennsylvania, in 1979 had a devastating impact on world's nuclear power industry. Afterwards, the US Nuclear Regulatory Commission strengthened the safety management practices of nuclear power and it has not reviewed an application to build a new nuclear power plant in the US since that time. The US has only recently started to loosen its restrictions on nuclear power construction. The US government has also brought about sweeping changes involving emergency response planning, reactor operator training, human factors engineering, radiation protection, and many other areas involved in the operation of nuclear power plants. Since the disaster on April 26, 1986 at the Chernobyl Nuclear Power Plant in the former Soviet Union, there was a downturn in nuclear power development worldwide. Only France, Japan, and a few other countries were engaged in the

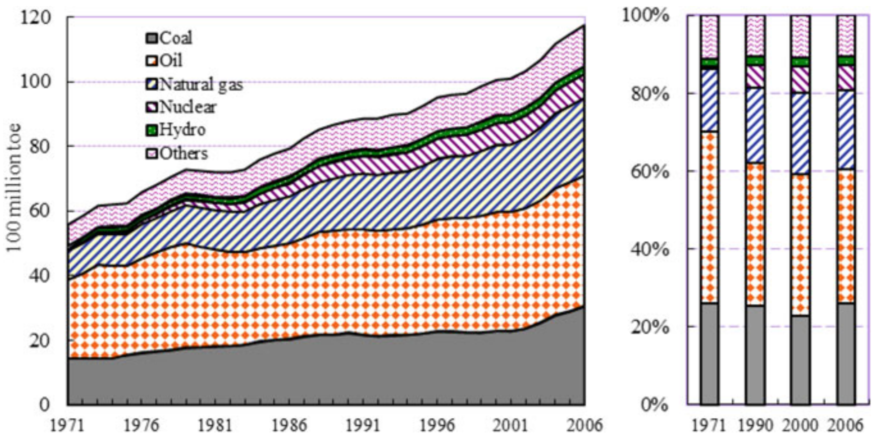

Fig. 1.11 Volume and structure of world energy production (1971–2006). *Data sources* IEA (2008) and authors' calculations

stable development of nuclear power. At the end of the 1980s, the ratio of nuclear power to energy production reached 70 % in France and Japan.

The ratio of coal production in Germany, UK, and Japan was very high in the early 1970s, but it decreased sharply in the following 20 years (Fig. 1.12). In 1975, Brazil implemented its National Alcohol Program and required that all fuels should be blended with 2–5 % ethanol. Since then, the percentage has been raised several times and the ratio of commercial renewable resources has gradually increased (Figs. 1.11 and 1.12).

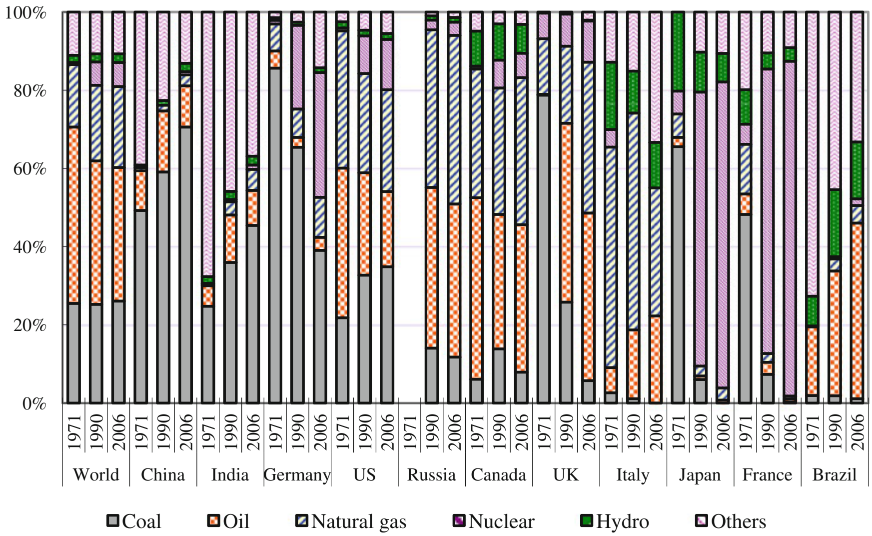

Fig. 1.12 Structure of energy production in some major countries in 2006. *Data sources* IEA (2008) and authors' calculations

(3) To tackle the increasingly prominent issues of energy safety, environmental pollution, and global climate change, renewable energy and other alternative energies have recently given high priority.
Since the late 1970s, the problems of energy safety, environmental pollution, and climate change were becoming increasingly severe. On the one hand, many countries (especially developed countries) have accelerated the development of alternative and renewable energies to counter these problems. On the other hand, despite the influence and constraints of national policy, as well as the cost and technology, the ratio of fossil fuels has continued to remain relatively high, even showing an increasing trend in some countries. Developed countries have many technological advantages over developing countries in renewable energy production, but the ratio of renewable energy, excluding hydropower, has not increased significantly in terms of primary energy production.
From 1970 to 2000, Germany, Italy, Japan, and other countries, which attached great importance to environmental protection or significantly lacked fossil fuels, have paid much attention to renewable electric power generation and its production ratio increased accordingly. In some countries, such as the United States, Canada, UK, and France, the ratio showed no increase and sometimes it even decreased. Since 2000, with the soaring fossil fuel prices and the increasing need for countries to adapt to climate change, renewable energy have gained unprecedented attention from both developed countries, such as the United States, EU, and Japan, and developing countries, such as China, India, and Brazil.
Even though the share of renewable energy in total energy production is still low, it is quickly increasing. Take wind power as an example. According to GWEC, the increase in newly installed capacity was 37.5 GW worldwide in 2009, an increase of 43 % from the previous year. Moreover, the rate has been increasing above 30 % for consecutive years. The main countries showing an increase in newly installed capacity include the United States, China, India, and Germany. The data from the China Electricity Council showed that wind power generation in China reached 276 billion kilowatts in 2009, an increase of 111.14 %. In addition, the IEA data indicates that solar power generation capacity in China also increased quickly, rising from 0.93 million boe in 2000 to 3.4 million boe in 2006.

(4) Due to the development of the global energy trade, smaller differences exist among the structures of the countries' primary energy consumption than among the structures of their primary energy production. For the major countries, the development trend of the former is similar to that of the latter. Through import, India, Germany, United States, Japan, Italy, and France have greatly improved and maintained the proportion of petroleum in terms of their total energy supplies through imports. Generally speaking, the share of petroleum shows a decreasing trend in the developed countries and an increasing trend in the developing countries, especially in such

petroleum-poor countries as China and India. The reasons are that developed countries have attached more importance to alternative energy as a result of energy safety considerations and developing countries have been in a stage of rapid development, where the need for petroleum resources has quickly increased. Therefore, the share of petroleum has shown an increasing trend. However, in recent years, as a result of the gradual increase in imports and the adjustment of the economic structure, the share of petroleum has started to decrease or has remained at the same level.

With the technological improvement in natural gas storage, the trade in natural gas has increased sharply. Now there are three major natural gas trading markets, which are based on the European pipeline transportation systems, Asia-Pacific LNG transportation network, and the North American pipeline transportation systems. The US, Germany, and Italy are the top three natural gas importers in the world, with combined imports representing 38 % of the world total (2008). Japan is the largest LNG import country at 95.4 billion cubic meters in 2008, or 42 % of the world total. As a better and more environment-friendly energy source than coal and petroleum, natural gas is expected to keep developing quickly in the next three decades. China, India, and other Asia-Pacific countries have shown considerable market potential and their shares of natural gas have much room for growth (Fig. 1.13).

(5) Comparing the differences among the structures of primary energy consumption by country, those among the structure of final energy consumption are smaller, with a more notable trend toward clean and low-carbon energies. The share of coal is high in terms of energy supply, but significantly lower in terms of energy end use. This is because coal is a low-efficient and environmentally unfriendly fuel, which could possibility cause serious ecological

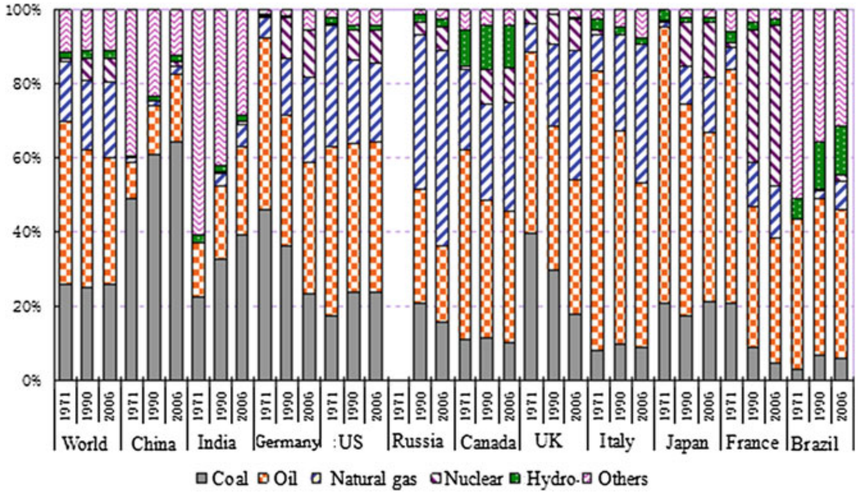

Fig. 1.13 Structure of primary energy supply in some major countries (1971–2006). *Data sources* IEA (2008) and authors' calculations

problems if used as final energy. As a result, both the government and consumer prefer to turn it into a cleaner fuel by using it to produce electric power, which is then transmitted to the end consumers. However, the proportion of petroleum-products consumption in the final energy consumption in countries such as China, India, and Brazil is increasing very fast with the rapid development of the transport sectors (including private vehicles).

As a clean and low-carbon energy resource, natural gas is considered to be relatively superior and has drawn increasing attention in recent years. China, India, Brazil, and other gas-poor developing countries have been inclined to increasingly use it as an end-use energy resource. However, even though natural gas in the developed countries is a widely used heating fuel and its share in terms of energy end use is high, its share has shown little growth in the past 40 years. This is because natural gas in these countries is mainly used for electricity generation.

As a result of social and economic developments, the ratio of electricity in energy end use has increased significantly in the developing countries, but in the already industrialized developed countries, there has been little room for such growth in electricity use. Thus, the ratio of electricity in energy end use has been increasing very slowly.

(6) The ratio of industrial energy use is generally increasing in the developing countries and decreasing in the developed countries.

The structures of final energy consumption and industrial production have been converging. Developing countries are in the process of urbanization and industrialization. Urban construction needs large amounts of material for infrastructure, especially high energy consuming products like iron and steel. Meanwhile, industrialization also needs large amounts of energy because the industry sector is energy-intensive. Hence, for developing countries, the ratio of energy end use in the industry sector is high and it shows an increasing trend. After the industrialization process is almost complete, the proportion of industry in the national economy begins to decline, and there is also a corresponding decline in the proportion of industrial energy (showing an inverted U-shaped curve). From 1971 to 2006, the share of industrial value-added in India increased from 21.6 to 29.5 %, and the share of energy end use by the industrial sectors increased from 23.6 to 28.8 %; in China, the share of industrial value-added fluctuated from 42.2 to 48.5 %, and the share of energy end use by the industrial sectors increased from 32.4 to 42.9 %; in Brazil, the share of industrial value-added increased from 38.2 % to a peak of 45.2 % in 1984, then decreased to about 26 % in the late 1990s. Only in the most recent ten years has it greatly increased. In terms of the share of energy end use by the industrial sector, it increased throughout 1970–1999 before fluctuating and reaching 39.9 % in 2006.

The developed countries, such as the US, are already industrialized and some of them have even started the process of deindustrialization in terms of their structure of energy consumption. The developing trend of the share of end

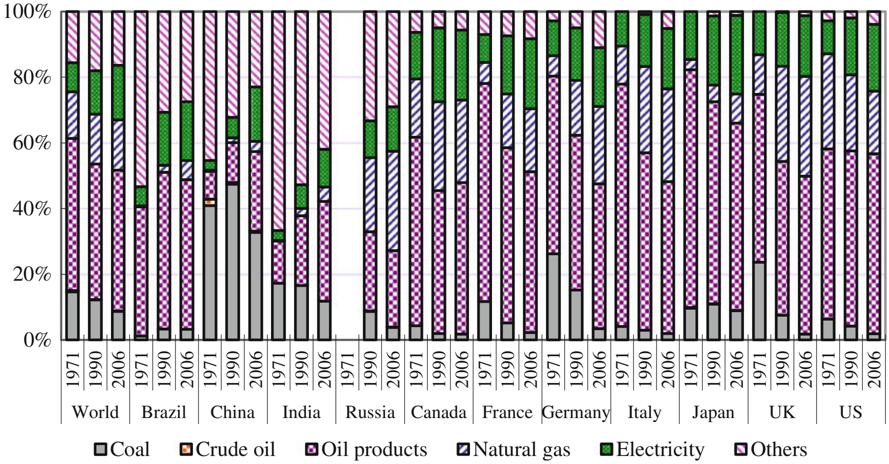

Fig. 1.14 Structure of energy end use in some major countries by energy source (1971–2006). *Data sources* IEA (2008) and authors' calculations

use energies by different sectors is the result of the combined effect of industrial restructuring and the promotion of superior energy sources in these countries. This is mainly because the output elasticity of the same thermal units of different energies is different. In general, the output elasticity of electricity is greater than that of coal and petroleum. This means that the output of electricity replaces much of the output of coal and petroleum using the method of thermal equivalents (Fig. 1.14).

(7) The share of end-use energy of the transport sectors is increasing slightly, with different driving forces for the developed countries and developing countries. The share of energy for living is decreasing in the developing countries while remaining unchanged in the developed countries.

In the early stage of industrialization, transportation development is the focus of the freight transport sector. In the middle and late stages, the focus is on private vehicles, which drives the growth of energy needs in the related sectors. For developed countries, the share of end use energy by the transport sectors varies greatly. On the one hand, this is because of the different cultures and government initiatives. For example, the people in Japan have a high level of environmental awareness and the government has policy institutions to restrict energy use. Therefore, the retail price of gasoline is 75 % higher than that in the US; thus, the share of end use energy for the transport sector is much lower (by 15 %) than that in the US. On the other hand, this is because of the different land areas among countries. The US is a country with a huge land area and extensive road networks; thus, the country uses much energy in the transport sectors. The reason why the share of energy use for living has a decreasing trend in the developing countries is mainly because of the increasing use of more efficient energy resources (Fig. 1.15).

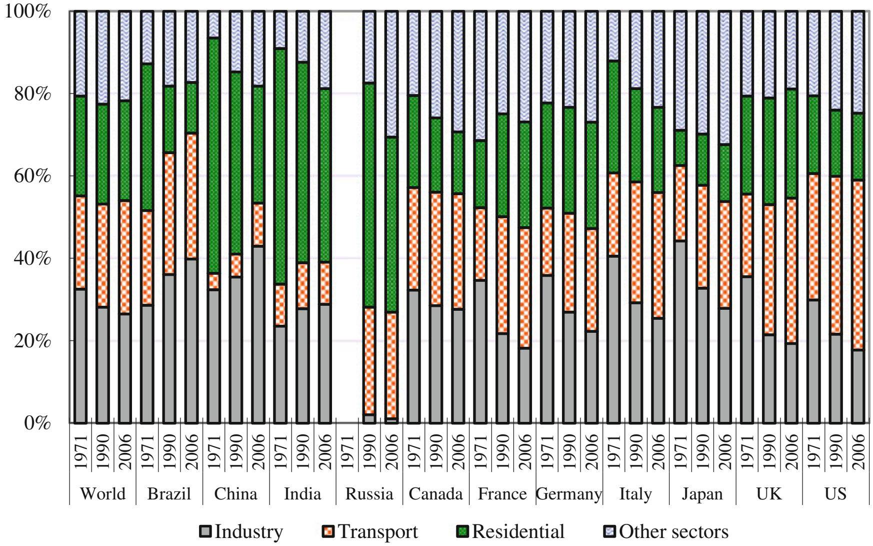

Fig. 1.15 Structure of energy end use in some major countries by sector (1971–2006). *Data sources* IEA (2008) and authors' calculations

(8) The structure of energy sources used to produce electric power is restricted by a country's energy resource endowment and shaped by national policy. The share of oil-fired power has sharply decreased. Moreover, the share of nuclear power increased from 1970 to 1985 in the developed countries and that of hydropower decreased in the developing countries.

China and India are rich in coal resources and their coal-fired power makes up a large proportion of electric power generation, with an increasing trend in their process of industrialization. In 2006, the proportion of coal-fired power was 80 and 68 %, respectively; and from 2000 to 2006, the proportion of newly added coal-fired electricity made up 82 and 61 % of their total additional electric power, respectively. Brazil is also rich in hydropower. Even though the proportion of hydropower decreased after 1990, it still makes up 80 % of the electric power in Brazil. In addition, the proportion of newly added hydropower made up 63 % of the total added electric power from 2000 to 2006. For Russia, which is rich in natural gas, gas-fired power constitutes nearly half of its electric power and the proportion of newly added gas-fired power plants constitute 74 % of the country's total additional electric power from 2000 to 2006. The case of Canada is similar to that of Brazil—the proportion of hydropower is large and the newly added electric power plants have mainly come from hydropower in recent years.

The proportion of oil-fired electric power was low for all of the selected major countries in 2006 and it showed a decreasing trend, which implies that the source of electric power had been replaced by other energy sources. For

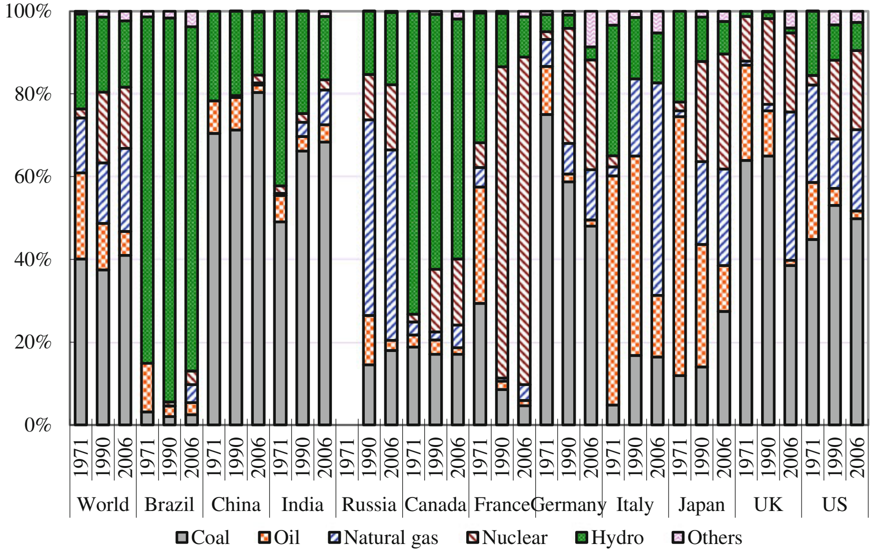

Fig. 1.16 Structure of energy sources used to produce electric power (1971–2006). *Data sources* IEA (2008) and authors' calculations

example, the proportion of oil-fired electric power in Italy decreased sharply from 48 % in 1990 to 15 % in 2006 and, accordingly, the proportion of gas-fired power increased by approximately 30 %. In the case of Japan, oil-fired power has been replaced by coal-fired, gas-fired, and nuclear power.[2] Compared with oil-fired and coal-fired power, gas-fired power saves space, water, cost, and time. Moreover, it is highly efficient, low in pollution, and operationally flexible. At the early stage of natural gas development, it was difficult to realize large-scale exploitation and trade natural gas internationally or inter-regionally because of the restrictions of storage technology. Instead, it was always consumed locally or transformed into electricity. With the rapid development of gas-storage technologies, natural gas pipelines, LNG carriers, and transition stations, large-scale natural gas exploitation, storage, and trading are possible. However, there have been significant differences among countries in terms of their policies towards gas-fired electric power. Therefore, the development of gas-fired electric power differs greatly by country. The US has neither restricted nor encouraged such development, but its gas-fired electric power has developed quickly in recent years. The proportion of newly added gas-fired power plants made up 83 % of the total added electric power from 2000 to 2006 (Fig. 1.16).

[2]After the Fukushima nuclear accident on March 11, 2011 the share of nuclear power in Japan has been close to zero, and electricity generated from oil and gas has increased. In 2010, electricity generated from nuclear power accounted for 26 % of Japan's gross electricity production, while the figures were 10 % in 2011, 1.5 % in 2012 and 0.9 % in 2013.

Although the proportion of coal-fired power is high in many countries, the coal-fired power generation technology and power generation efficiency keep improving, and the associated pollution keeps falling. Nonetheless, with increasing concerns over climate change, wind power, biomass electricity, and other renewable energy resources are developing very quickly. They have the potential to replace coal-fired power and other traditional power to some extent. For instance, Germany is the leading country in renewable energy development because its wind power and biomass electricity have developed rather quickly. From 2000 to 2008, the proportion of these two energy sources made up 92 % of its total newly added electric power. In the industrialization process, the development of biomass energies and other low-carbon electricity technologies to generate electric power has resulted in more diversified energy sources.

(9) For the developed countries, the proportion of industrial electricity use in terms of the total electricity end use keeps decreasing, the proportion of domestic electricity use remains stable, and the proportion of electricity use by other sectors is improving. For the developing countries, the proportion of industrial electricity use is high and the proportion of domestic electricity use is slightly increasing.

The developing countries are undergoing the process of industrialization in which a large proportion of industrial sectors are showing an increasing trend. Industries related to iron and steel, nonferrous metals, building materials, and petrochemical are electricity-intensive. In 2006, the proportion of the total electricity end use for these four industries amounted to 40.5 % in China, 32.4 % in Russia, 24.2 % in Brazil, and 12.3 % in the US and UK. From the perspective of the development trend, the proportion of electricity end use by these industries shows a decreasing trend in all major countries except Russia (the data for India is missing); subject to the stage of development, the trends in China and Brazil have been decreasing very slowly, with the exceptions of an increase in certain years (Figs. 1.17 and 1.18).

China is the largest cement-, iron-, and steel-producing country in the world, with a huge amount of electricity use. Its crude steel production was 0.5 billion tons in 2008, or 37 % of the world total, and cement production was 1.4 billion tons, or 50 % of the world total. With an improvement in living standards in developing countries, such as China, India, and Brazil, the proportion of domestic electricity use in these countries has shown an increasing trend. In contrast, the US, UK, and other highly developed countries, where household appliances have already been widely adopted, domestic electricity use has increased very slowly. Therefore, the proportion of domestic electricity use in these countries has remained almost stable in recent years. Moreover, Japan, France, and Germany had undergone a fast growth rate in domestic electricity use in the 1960s and 1970s, after recovering from World War II, followed by stable growth in the mid-1980s. In the past 40 years, the proportion of the added value from tertiary industry

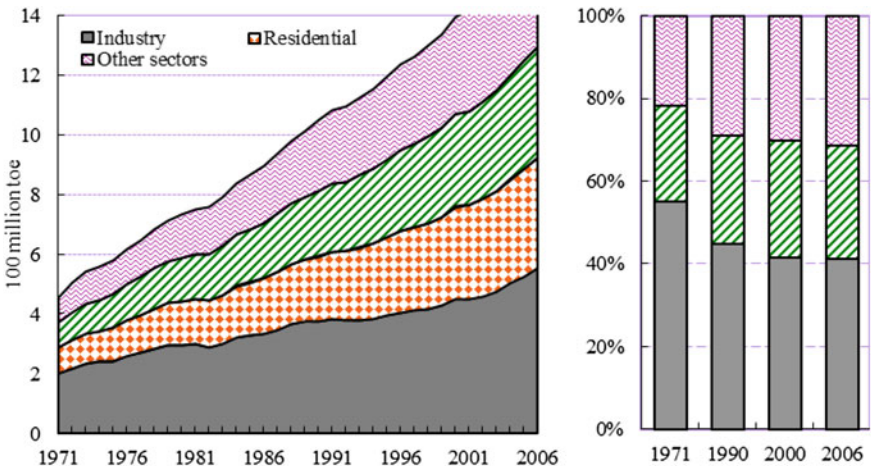

Fig. 1.17 Structure of global electricity consumption by industry (1971–2006). *Data sources* IEA (2008) and authors' calculations

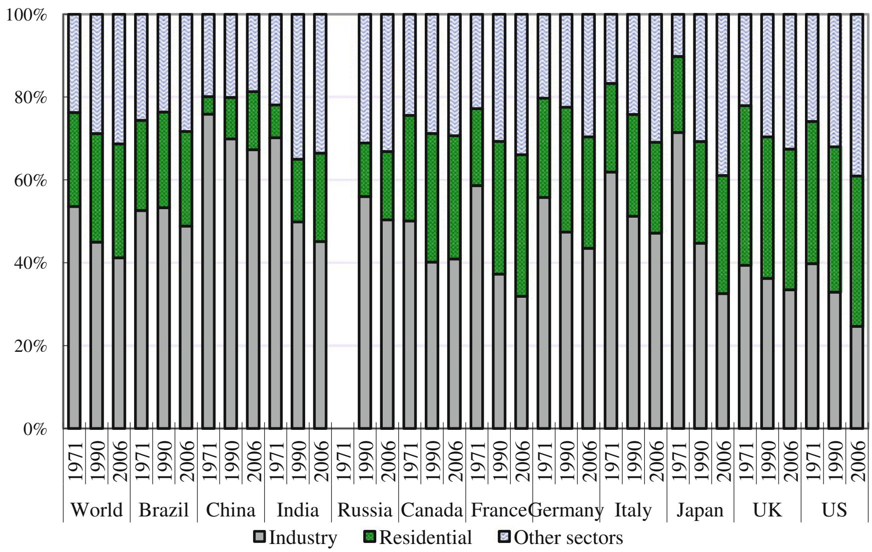

Fig. 1.18 Structure of electricity end use consumption by sector in the major countries (1971–2006). *Data sources* IEA (2008) and authors' calculations

has been increasing and the proportion of electricity use by the third industry has also been increasing in the developed countries (Fig. 1.19).

(10) The proportion of biomass energy use for domestic energy use has decreased sharply while the proportion of gas, electricity, and other clean energy has continued to increase.

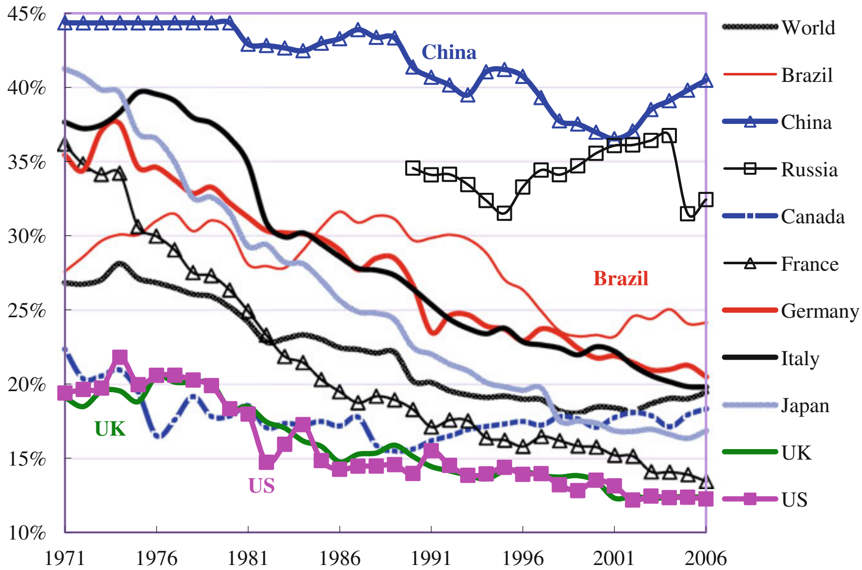

Fig. 1.19 Proportion of electricity consumption by the second industry (*Iron and steel, nonferrous metals, building materials, and petrochemicals*) in the major countries (1971–2006). *Data sources* IEA (2008) and authors' calculations

The urbanization level is low in the developing countries and many rural residents use biomass, such as straw, firewood, and biogas, for fuel and heat as major sources of energy. Due to low combustion efficiency, the high proportion of residential energy use, and the use of unclean biomass energy, there are serious problems of indoor air pollution. However, with economic development and the increasing availability of coal, liquefied petroleum gas, electricity, and other commercial energy resources, the proportion of biomass energy is decreasing.

The proportion of domestic biomass energy use in China decreased from 79.5 % in 1971 to 64.6 % in 2006 and that in India and Brazil decreased from 92.7 to 78.5 % and from 85.4 to 37.3 %, respectively, during the same period. The proportion of coal use showed an upward trend, followed by a downward trend in China. This is mainly because coal resources initially replaced biomass energy and then they were replaced by electricity, liquefied petroleum gas, and natural gas. The proportion of electricity energy use quickly increased in Brazil. France is among the top countries in biomass energy production with the proportion showing a decreasing trend while remaining at a level of 17.1 % in 2006. In most developed countries, the proportion of domestic natural gas use has increased and natural gas and electricity have become the principle domestic energy sources (Figs. 1.20 and 1.21).

The structure of energy use is influenced by technological development and economic development, which have a direct impact on carbon dioxide

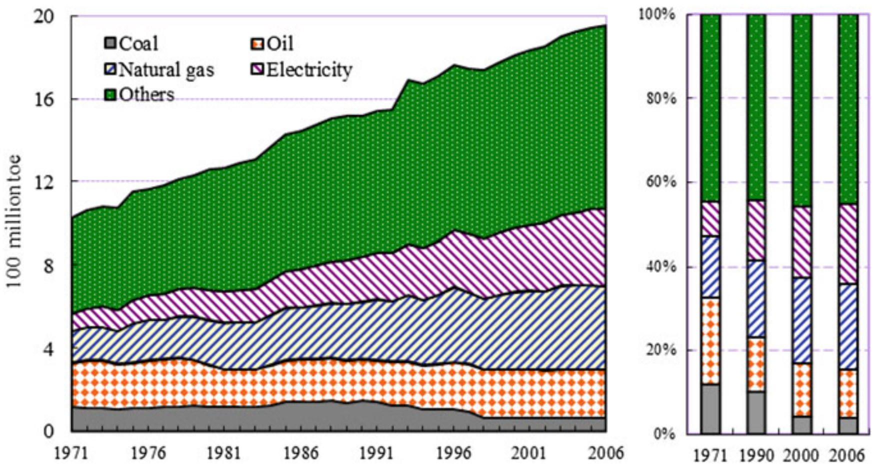

Fig. 1.20 Structure of global domestic energy use (1971–2006, excluding private vehicles). *Data sources* IEA (2008) and authors' calculations

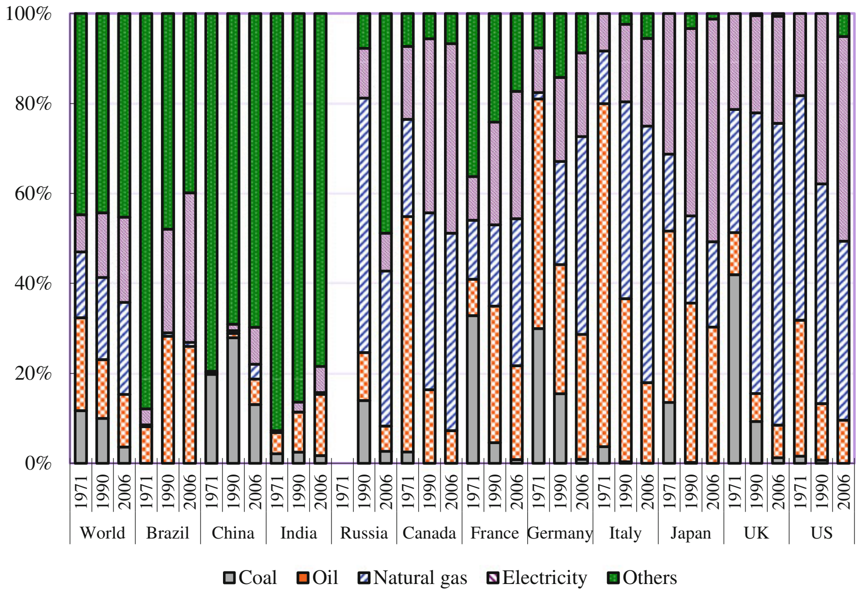

Fig. 1.21 Structure of domestic energy use in the major countries (1971–2006, excluding private vehicles). *Data sources* IEA (2008) and authors' calculations

emissions. From the history of energy use in the major countries, we find that the structure of primary energy production was mainly restricted by energy resource endowments, became more diversified by the development of international energy trade, and then developed toward a clean industry with low-carbon emissions due to technological improvements. Owing to the different development stages, the energy structures of the developing and developed countries are very different. Government policy initiatives have greatly influenced the consumption of nuclear power and natural gas. The increasing concerns over energy safety, environmental deterioration, and climate change have accelerated the development of wind energy, solar energy, biomass electricity, and other clean energy sources.

1.4 Review of China's Energy Development

1.4.1 Rapid Economic Growth with a Lower Energy Consumption Growth Rate

Since 1949, and especially after 1978, GDP and energy consumption have been rapidly increasing in China. According to NBS-DCS (2010), NBS (2010a), and our estimations, China's GDP has increased from 380 billion yuan in 1953 to 1530 billion yuan in 1978, and then to 28,500 billion yuan in 2009 (at constant 2005 prices). The average growth rates during the periods of 1953–1978 and 1979–2009 were 5.8 and 9.9 %, respectively. In addition, energy consumption has increased from 54 million tons of coal equivalent in 1953 to 571 million tons in 1978 and then to 3.066 billion tons in 2009, with an annual growth rate of 9.9 % during the 1953–1978 period and 5.4 % during the 1979–2009 period.

According to the data by the National Bureau of Statistics and General Administration of Customs, the economic growth rate in 2009 was 9.1 % and energy consumption was 3.066 billion tons of coal equivalent, an increase of 5.2 % over the previous year. On the one hand, coal consumption was 3.02 billion tons, an increase of 9.2 %, of which 103.44 million tons represented net imports—the first time China was a net importer. On the other hand, crude oil consumption was 0.38 billion tons, an increase of 7.1 %, in which net imports of 0.199 billion tons represented an increase of 13.6 %. Moreover, natural gas consumption was 88.7 billion cubic meters, an increase of 9.1 %, and electricity consumption was 3714.6 billion kWh, an increase of 6.3 % (Table 1.9).

China is rich in coal resources. Limited in energy resources, coal-based high-carbon energy make up a very large proportion of the country's primary energy consumption. Coal consumption initially amounted to more than 90 % of its primary energy consumption. With the development of the petroleum, natural gas, and hydropower industries, the proportion of coal consumption has decreased domestically. Meanwhile, the proportion of electricity consumption has gradually increased from 3 % in 1978 to 9 % in 2009. Consequently, one can conclude that the structure of energy production and consumption in China today is "coal-based, diversified development." However, the extensive use of coal resources has been accompanied by serious environmental deterioration and greenhouse gas emissions (Fig. 1.22).

Table 1.9 GDP and energy consumption in China (1953–2009)

Year	Energy consumption	GDP	Energy consumption per GDP	Year	Energy consumption	GDP	Energy consumption per GDP	Year	Energy consumption	GDP	Energy consumption per GDP
1953	0.54	0.37	1.44	1972	3.73	1.08	3.46	1991	10.38	4.70	2.21
1954	0.62	0.39	1.60	1973	3.91	1.16	3.37	1992	10.92	5.37	2.03
1955	0.70	0.42	1.67	1974	4.01	1.19	3.38	1993	11.60	6.12	1.90
1956	0.88	0.48	1.84	1975	4.54	1.29	3.52	1994	12.27	6.92	1.77
1957	0.96	0.50	1.91	1976	4.78	1.27	3.76	1995	13.12	7.67	1.71
1958	1.76	0.61	2.88	1977	5.24	1.37	3.83	1996	13.52	8.44	1.60
1959	2.39	0.66	3.60	1978	5.71	1.53	3.74	1997	13.59	9.23	1.47
1960	3.02	0.66	4.55	1979	5.86	1.64	3.56	1998	13.62	9.95	1.37
1961	2.04	0.48	4.23	1980	6.03	1.77	3.40	1999	14.06	10.71	1.31
1962	1.65	0.45	3.64	1981	5.94	1.87	3.19	2000	14.55	11.61	1.25
1963	1.56	0.50	3.11	1982	6.21	2.03	3.05	2001	15.04	12.57	1.20
1964	1.66	0.59	2.81	1983	6.60	2.26	2.93	2002	15.94	13.72	1.16
1965	1.89	0.69	2.72	1984	7.09	2.60	2.73	2003	18.38	15.09	1.22
1966	2.03	0.77	2.64	1985	7.67	2.95	2.60	2004	21.35	16.61	1.28
1967	1.83	0.72	2.53	1986	8.09	3.21	2.52	2005	23.60	18.5	1.28
1968	1.84	0.69	2.65	1987	8.66	3.58	2.42	2006	25.87	20.8	1.24
1969	2.27	0.81	2.80	1988	9.30	3.98	2.33	2007	28.05	23.8	1.18
1970	2.93	0.97	3.02	1989	9.69	4.15	2.34	2008	29.14	26.1	1.12
1971	3.45	1.04	3.33	1990	9.87	4.30	2.29	2009	30.66	28.5	1.08

Units: 10^8 tce, 100 million yuan, tce per 10^4 yuan, in constant 2005 prices. The data for GDP in 2005–2008 has been corrected by the National Bureau of Statistics after the second national economic census and the data for energy consumption since 1996 has been revised to avoid the negative growth in energy consumption

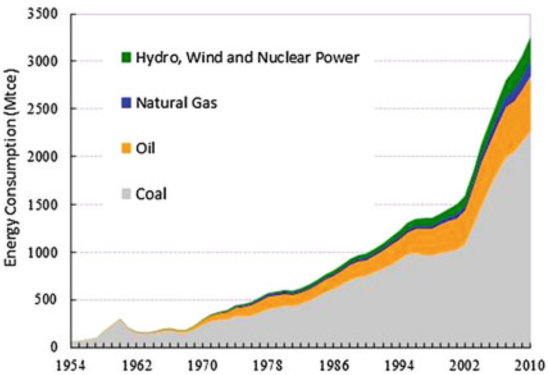

Fig. 1.22 Structure of energy consumption in China (1954–2010). *Data sources* NBS-DCS (2010), NBS (2010b) and authors' calculations

Even though our conclusion of a coal-centered energy consumption structure is based on energy quantity, attention also needs to be paid to coal's magnitude in terms of value. According to cost accounting, the price per unit of calorific value of crude oil is much higher than that of coal, so coal consumption does not have an absolutely dominant position in China's structure of energy consumption. As a result, the cost of crude oil represented the highest proportion in some years, so this fact should be seriously recognized in the research by energy economists.

1.4.2 Energy Supply Maintains a Rapid Growth Rate While the Energy Self-sufficiency Rate Has Declined

Energy safety has always been a government's priority. Energy production in China has maintained its fast pace of growth in general and has achieved economic development and satisfied people's living requirements. However, the data show that the production of energy is not completely synchronized with economic development (Table 1.10). Before 1996, energy production lagged behind economic growth, which can be presented from the constant power shortages and this discord has affected the economic and social development to some extent. As a result of various reforms undertaken since 1994, production in the energy industry has accelerated. Since 1998, the Chinese government has initiated two projects to construct and upgrade the rural power grids at a national scale, which almost solved the problems of poor coverage, insufficient power supply, and poor stability in the rural areas. Since 2007, the situation of energy shortages has been improved at the national scale, even though energy shortages have sometimes occurred in local areas since 2002 due to the economic cycle. At present, the Chinese government is promoting a new round of projects to upgrade the rural power grids.

According to the data from the National Energy Administration (2010) and the National Bureau of Statistics (2010b), raw coal production in 2009 was 2.97 billion tons (an increase of 6.1 %), crude oil production was 0.189 billion tons (a decrease

Table 1.10 Chinese energy production in specific years (1949–2009)

Year	Raw coal (10^4 tn)	Crude oil (10^4 tn)	Natural gas (10^8 cu m)	Nuclear power (10^8 kW h)	Hydropower (10^8 kW h)	Wind power (10^8 kW h)	Primary energy production (10^4 tce)	Electricity (10^8 kW h)
1949	320	12	0.07	0	7	–	2374	43
1956	1100	116	0.26	0	35	–	8242	166
1959	3690	373	2.9	0	44	–	27,161	423
1962	2320	1131	11	0	104	–	18,824	676
1966	4830	8716	101	0	456	–	50,340	2031
1976	6180	10,405	137	0	446	–	62,770	2566
1978	78,923	11,461	124	0	868	–	77,855	3770
1984	111,638	14,210	158	0	1307	–	107,256	7539
1992	137,282	16,074	227	144	1960	–	132,410	11,356
1997	138,800	16,700	327	251	2880	–	133,460	16,540
2005	235,000	18,135	493	531	3970	15	216,219	25,003
2009	297,300	18,949	830	701	6156	269	275,000	37,147

The years selected are Chinese economic turning points or the year when important policies were implemented of 0.4 %), natural gas production was 85.17 billion cubic meters (an increase of 6.1 %), and coal-bed methane extraction was 7.18 billion cubic meters and its effective utilization was 2.35 billion cubic meters (an increase of 23.8 and 36.6 %, respectively).

Owing to existing energy resource reserves, the difficulties of exploitation, and the constraints of the existing levels of technology, Chinese crude oil production has almost reached its limit and is expected to stay at a level of 0.19 billion tons annually in the near future. Since 2002, the proportion of coal production in the total energy supply has increased. Electricity has long been the focus of energy investment, amounting to 60 % of the total. The development of natural gas has become increasingly important, so its growth rate in terms of production has remained above 18 % for several years. The improvements in technology, completion of property rights legislation, and growing concern over the utilization of natural resources are expected to accelerate the pace of exploitation and utilization of coal-bed methane. According to the China Electricity Council (CEC 2010), the total electricity capacity reached 0.874 billion kW at the end of 2009, an increase of 10.23 % since the end of 2008.

Even though investment in the energy industry developed quickly, petroleum imports increased sharply due to even faster demand growth, and the degree of external dependence reached 50 %. With the second phase of the "West–East Pipeline" project being put into operation in combination with the development of LNG storage and transport technologies, and the expansion of LNG transit stations, natural gas imports will grow in the future. According to Chinese customs, LNG imports were 5.532 million tons in 2009, an increase of 65.8 %.

In recent years, with the changes in regional resource potential and policy guidance, the regional shares of raw coal and crude oil production have changed a lot (Table 1.11). For example, to become the basis of its national energy production, the share of raw coal production in Inner Mongolia increased from 8.0 % in 2002 to 20.3 % in 2009. With coal production at 0.6 billion tons in 2009, Inner Mongolia has taken the place of Shanxi as the top coal producing province.

Table 1.11 Regional ratios of raw coal and crude oil production in China

Raw coal			Crude oil		
Province	2002	2009	Province	2002	2009
Hebei	5.5	2.9	Tianjin	6.9	12.1
Shanxi	21.9	20.0	Liaoning	7.6	5.3
Inner Mongolia	8.0	20.3	Heilongjiang	28.4	21.1
Heilongjiang	5.3	3.0	Shandong	15.1	14.9
Anhui	5.5	4.3	Guangdong	7.1	7.1
Shandong	11.7	4.8	Shaanxi	6.0	14.2
Henan	8.9	7.8	Xinjiang	11.4	13.3
Shaanxi	5.3	10.0			

Unit: %

Moreover, the economic growth rate in Inner Mongolia has remained in first place for eight years among all the provinces and regions of China due to the stimulation of the development of its energy industry. In addition, the raw coal production in Shanxi province also increased sharply, and it became the third-largest coal-producing province. Meanwhile, the coal production in Shandong and Hebei provinces has decreased sharply. With the decline in oil production from the Daqing oilfield, the share of oil production from Heilongjiang province decreased a lot, from 28.4 % in 2002 to 21.1 % in 2009, and the province's crude oil production in 2009 was only 40 million tons. However, crude oil production in Shaanxi province quickly increased, reaching 0.27 billion tons in 2009.

1.4.3 Less Carbon-Intensive and Cleaner Energy Structure and More Energy-Intensive Economic Structure

Since 2002, the processes of industrialization, urbanization, expanding markets, internationalization, and information technology have accelerated. The economy continues to grow quickly, especially the energy-intensive industries, so it is characterized by "energy-intensive" growth. Even though the governments have always stressed the transformation of various economic growth modes (later referred to as "economic development modes"), the actual economic performances have been far from expected as a result of objective factors, such as the low stage of development, and subjective factors, such as incoherent goals among different levels of government. The government has made great efforts toward reducing excess productive capacity, but iron and steel production and other industries are still expanding quickly. The average growth rate of steel products was 8 % higher than that of the national economy during the 2002–2009 period. Although noteworthy, a controversial problem is "whether or not the productive capacity was excessive." The new construction in rural areas and the upgrading of people's consumption patterns also boosted the development of some energy-intensive industries. For example, in the automobile industry, production was 13.795 million in 2009, an increase of 48.2 %, and the number of private vehicles was 26.05 million, an increase of 33.8 % (NBS 2010a).

In response to surging energy prices, the increasing external dependence on oil resources and more serious warnings about global warming, the government has initiated many policies to promote the development of renewable or clean energies, such as hydropower, wind power, solar power, biomass energy, and nuclear power. At the end of 2009, the installed capacity of thermal power in China was 0.652 billion kW (a decrease of 1.5 % compared with the end of 2008), representing 74.6 % of the total installed capacity of electric power. The installed capacity of hydropower was 0.197 billion kW (an increase of 0.74 % from the previous year),

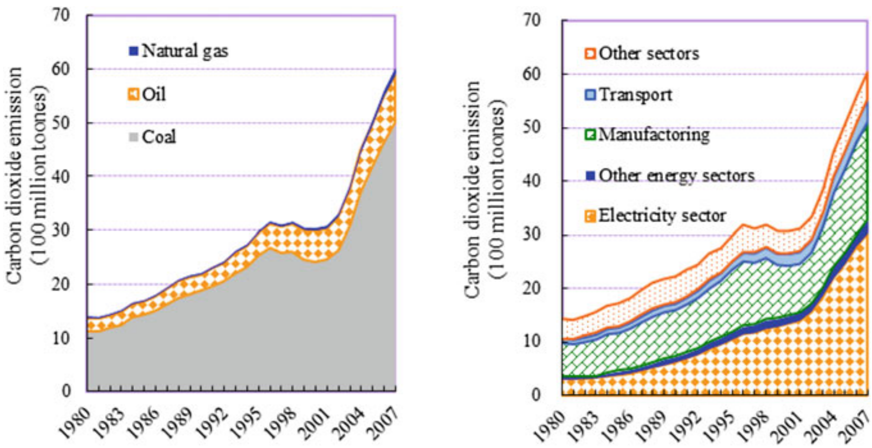

Fig. 1.23 China's CO_2 emissions from the burning of fossil fuels (1980–2007). *Data source* IEA (2009a)

representing 22.5 % of the total installed capacity of electric power. The capacity of the wind power grid was 16.13 million KW, an increase of 92 %, and the construction of nuclear power also increased, with a total capacity of the projects under construction of 23.05 million KW.

1.4.4 CO_2 Emissions Grow Rapidly and CO_2 Abatement Pressures Increase

Restricted by the stage of development and existing resource endowments, carbon dioxide released from the burning of fossil fuels has increased sharply in recent years. According to IEA (2009a), carbon dioxide emissions from the burning of fossil fuels were over 6 billion tons in 2007, out of which 83 % was from the burning of coal resources and 50 % was from the electric sector (Fig. 1.23). Supposing that the carbon dioxide emissions from the electric sectors are evenly distributed among all of the other sectors, the proportion of emissions from the manufacturing sector would be 60 % of total emissions (that in the OECD countries was less than 30 %). Carbon dioxide emission increased by 5.5 % annually during the 1980–2007 period while emissions per unit of GDP decreased by 4.2 % annually, for an accumulated decrease of 47 % from 1990 to 2005. Nevertheless, it is a tough task for China to fulfill its promise to decrease carbon dioxide emission intensity by 40–45 % during 2005–2020.

1.5 New Changes and Trends in China's Energy Development

1.5.1 Reform of the Energy Management Mechanism Keeps Moving

Since the establishment of the Ministry of Energy and Industry in 1949, there have been more than ten major adjustments in the Chinese energy regulatory systems. The most recent adjustments include the establishment of the National Energy Administration under the regulation of the National Development and Reform Commission in 2008, which has integrated the responsibilities and rights under the National Development and Reform Commission, State Energy Bureau, and the nuclear power administration office of the State Commission of Science and Technology for the National Defense Industry. This includes formulating and implementing energy development plans and industrial policies, promoting institutional reform in the energy sector, administering the energy sectors, and all other responsibilities related to energy regulations. Another adjustment was the establishment of the National Energy Commission in 2010 to further stress the importance of the energy problem and to facilitate strategic decisions and comprehensive arrangements. The specified responsibility of the commission is to determine a national energy development strategy, address significant issues concerning energy security and energy development, and coordinate major programs of domestic energy development and global cooperation. The establishment of the National Energy Commission came as a much-anticipated move to coordinate and devise a comprehensive national energy policy and energy regulation system in China. As energy is a rather extensively evolving industry, its regulation needs the cooperation of many departments and the energy regulation system needs further improvement. It is noteworthy that the first National Energy Working Group meeting was held in February 2009, which deployed the key work of the future energy regulations.

The government has made a great effort in improving the energy-related legal system. On December 26, 2009 the National People's Congress and its standing committee passed the Renewable Energy Law of the People's Republic of China (Amended), which has been in effect since April 1, 2010. This law outlines the requirements for the overall planning of various kinds of renewable energy sources, establishes the acquisition systems with complete guarantees, and proposes fund raising. At present, there is pressure to draft this law as a foundation of the energy field.

On December 18, 2008 the notice of reform on oil prices and taxes was introduced by the State Council and included cutting the tax on oil prices, canceling six kinds of charges, including a road toll, gradually and orderly eliminating a secondary road fee to service the government debt, and increasing the tax per unit of refined oil product consumption. On May 8, 2009 the National Development and Reform Commission specified a new management policy for the oil price, in which the price contributes toward the regulation of the traffic tax system. Further, it promoted energy savings, emission cuts, and the price formation mechanisms of oil. At present, natural gas price reform is facing a rather fierce situation, where domestic development is largely dependent on such reform. Although the domestic crude oil price has fully converged with the international price, the import trade is still restrained by a monopoly. In 2009, state-owned enterprises imported 190 million tons of crude oil, of which 93 % was taken by them.

The main coal producing areas have successively promoted the merger and reorganization of coal enterprises. In September 2008, Shanxi province issued an executive opinion about further expediting the coal enterprises' mergers and reorganizations and calling for production within the province of more than 3 million tons per year by the end of 2010 and a maximum of 1500 coal wells. Furthermore, there should be two or three very large companies producing at a level of 100 million tons and three to five large companies producing at a level of 50 million tons for a combined 75 % or more share of total production. In February 2010, the merger and reorganization of Shanxi coal enterprises was nearly complete and it helped to increase the efficiency of the exploitation and utilization of coal resources and to cut the number of accidents as well. Of course, time will tell concerning the far-reaching influence on the socioeconomic development of Shanxi province and even China. Hainan province also experienced a similar situation in 2010.

The year 2010 was the last year of the "Eleventh Five Year Plan," but also the beginning of the "Twelfth Five Year Plan" and a new round of long-term energy development plans is gradually emerging. In 2009, China endeavored to increase the share of non-fossil fuels in its total energy consumption to around 15 % by 2020 and carbon dioxide emissions hit the target of a 40–45 % decrease from 2005 levels, with the contribution of energy savings and efficiency reaching 85 %.

1.5.2 Energy Demand Growth Rate Decreased Due to the Business Cycle

The international financial crisis, domestic economic cycle, and an imbalance in the economic structure slowed down the pace of China's economy in 2008 that further led to a decrease in the demand for energy, especially electricity (see Fig. 1.24). According to data from the National Statistical Bureau, since March 2008, growth in electricity generation gradually decreased compared with previous months, reaching −9.6 % in November 2008, but growth returned to 25.9 % by the end of 2009, with the introduction of the policy on expansion of domestic demand. It is difficult to understand that negative growth in electricity could still sustain a positive economic growth rate of 9 % based on a semi-qualitative analysis of economic growth and structural changes. Because electricity maintains an important position among government departments, the data are relatively prompt and accurate, and it is essential to develop a deep understanding of the relationship between electricity and the economy in terms of the development of electricity and economic decision making.

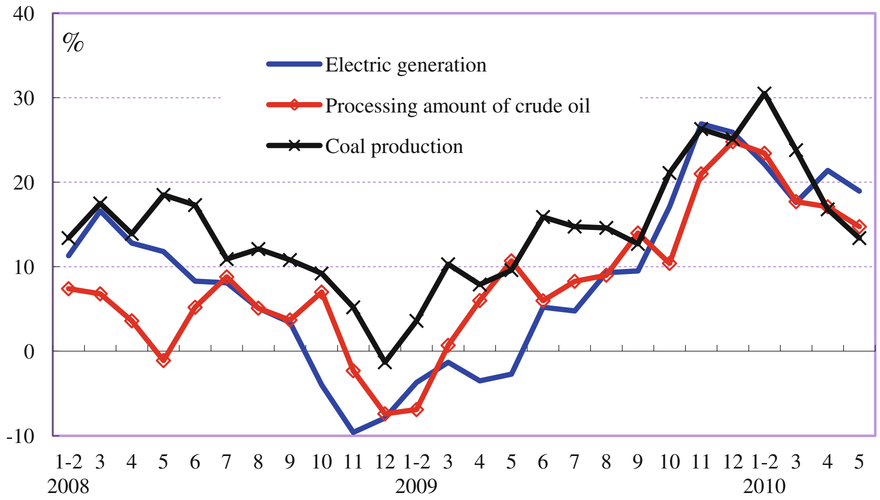

Fig. 1.24 Monthly growth rate of energy output (2008–2010). Data for January and February are combined to remove the impact of the Spring Festival

To face the financial crisis, governments at all levels introduced a series of economic stimulation policies to expand domestic demand, among which the fixed asset investment based on building projects takes a major role in substantially increasing energy demand in 2009. According to measurements and calculations by the World Bank, the year 2009 witnessed the fastest growth in actual investment (18.3 %) since 1993. Due to additional investment, new energy capabilities and ongoing use of private cars, it is estimated that energy demand will continue to be high.

1.5.3 Energy Supply Diversification Is Accelerating

Considering a farsighted approach, to satisfy the reliance on fossil energy, protect the environment, guarantee the safety of supply, and counter climate change, China's energy supply must become more diversified, in terms of variety and source.

China has the greatest growth in new and renewable energies than any other country. From 2005 to 2008, the growth of renewable energy was 51 %, or 14.7 % annually. Consumption reached 250 million tons of coal equivalent in 2008. China ranked first in the world in terms of installed hydropower capacity, nuclear power capacity under construction, the coverage of solar water heating panels, and photovoltaic power capacity (Wen 2009). In September 2009, the Chinese government proposed that it would endeavor to increase the sale of non-fossil fuels for primary energy consumption to approximately 15 % by 2020. China also has the largest building program for nuclear power in the world, where installed hydropower capacity will reach 70–80 million KW. In addition, wind power in China is developing quickly. Newly added installed wind power capacity was 13,000 MW in 2009, representing 34.7 % of global growth. Domestic wind power research has made substantial technical progress by building a wind turbine generator of 3 MW. According to the national rural biogas project for construction planning for the 2006–2010 period (Department of Agriculture 2007), the increase in biogas use throughout the country during the "Eleventh Five Year Plan" should include an additional 22 million households and reach a total of 40 million households by 2010, accounted for 29 % of appropriate households. To positively counter worldwide climate change, the Chinese government proposed in December 2009 that CO_2 emission per unit of GDP should decrease by 40–50 % by 2020 compared with 2005.

On December 14, 2009, the China–Asia natural gas pipeline officially came into use. The pipeline is more than 1800 km in length, starts from the border of Turkmenistan and Uzbekistan and flows through Uzbekistan and Kazakhstan to Korgas in Xinjiang province, China. It is also linked to the second line of a natural gas transmission project from west to east China, which will be the first project to introduce offshore natural gas; for example, 30 billion cubic meters annually from Turkmenistan. The second line is not being put into use until the end of 2011, making the proportion of natural gas for energy consumption rather remarkable. In addition, there are more receiving stations of LNG in China and better LNG storage and transportation networks. Since the first LNG vessel in 2008, the production of LNG vessels made in China is experiencing an upward trend. In 2009, imports of LNG were 5.8 million tons, or an increase of 67 %. Moreover, in 2009, China became a net importer of coal for the first time by importing more than 0.1 billion tons and this trend is predicted to grow.

The trend of multiple imports of crude oil is relatively slow. In 2009, Saudi Arabia, Angola, and Iran were the three main sources of crude oil, accounting for 48 % of total imports.

1.5.4 Striking Advances in Energy Conservation Development

The year 2010 was the last year for the Chinese government to achieve its energy saving targets in the "Eleventh Five-Year Plan." On the basis of the preliminary data, nationwide energy consumption per unit of GDP had decreased by a cumulative 15.6 % compared with that in 2005, representing three quarters of this target. The decrease in 2009 alone was 3.6 %, so there is hope that the goal would be achieved by the end of 2010. According to the National Development and Reform Committee (NDRC 2010), Beijing and Tianjin had fully reached their targets by the end of 2009 while a total of 22 regions, including Hubei, Hunan, and Guangxi had completed 80 % of their targets. Meanwhile, Tibet, Anhui, Jilin, Guizhou, and

Table 1.12 Fulfillment of energy saving target by province during the Eleventh Five-Year Plan (2009)

Province	Accumulative reduction rate of energy consumption per 10 thousand GDP	Fulfillment of target of energy saving during the 11th Five-Year Plan	Province	Accumulative reduction rate of energy consumption per 10 thousand GDP	Fulfillment of target of energy saving during the 11th Five-Year Plan
Beijing	23.34	119.14	Hubei	18.46	91.43
Tianjin	20.07	100.39	Hunan	18.2	90.02
Hebei	17.21	84.62	Guangdong	13.77	84.99
Shanxi	18.28	81.23	Guangxi	13.48	89.1
Inner Mongolia	18.82	83.9	Hainan	7.12	57.75
Liaoning	16.64	81.55	Chongqing	17.13	84.19
Jilin	17.47	77.29	Sichuan	16.36	80.05
Heilongjiang	16.39	80.23	Guizhou	15	72.84
Shanghai	17.12	84.14	Yunnan	14.11	81.63
Jiangsu	17.51	86.28	Tibet	9.6	78.99
Zhejiang	17.36	85.42	Shaanxi	17.24	84.78
Anhui	16.13	78.82	Gansu	17.32	85.21
Fujian	13.22	81.32	Qinghai	12.53	71.84
Jiangxi	16.68	81.79	Ningxia	16.36	80.04
Shandong	18.51	82.39	Xinjiang	8.55	40.05
Henan	17.03	83.65	China	15.56	–

Numbers are calculated by author based on the preliminary data of GDP and energy consumption issued by State Statistical Bureau

Qinghai had satisfied 70–80 % of their targets and those for Hainan and Xinjiang were less than 60 % (see Table 1.12). Based on historical experience, it is estimated that almost all provinces would reach, or even exceed, their energy-saving targets, except for some provinces experiencing particular circumstances (e.g., earthquakes, social unrest, small-scale economies with relatively low energy consumption, and so on) that may only come close to their targets.

According to preliminary data, energy consumption per unit of GDP increased by 0.09 % in the first half of 2010 compared with that in the previous year, a figure that is not particularly optimistic. Based on historical data, the annual figure is therefore expected to decline.

To evaluate the fulfillment of the energy-saving targets in each province, we should not only accurately measure the total energy consumption but also consider the change in its structure and the incomplete substitution of various energy resources. Otherwise, it may not be accurate, resulting in the formulation of improper incentive mechanisms. In accounting for total energy consumption based on the equal value assessment, the reason why some provinces only partially reached their targets could be that coal became a substitute for oil, so there was a relatively higher growth rate for coal in terms of consumption. Ideal energy-efficiency indicators are supposed to stimulate, control, and analyze the data before, during, and after the period of interest, respectively. If so, then the users of energy will pursue the minimum cost and maximum profit, and the government will achieve its energy-saving target.

How to promote the "Twelfth Five-Year Plan" and select the appropriate indicators and criteria is important in reducing the energy-saving cost, increasing economic efficiency, and promoting equity and development. China has an unbalanced regional development, which is reflected in each province's developmental stage, natural resource endowment, geographic location, labor conditions, and so on. These regional variations have the potential to cause differences in the cost related to reducing the energy consumption per unit of GDP among regions in the same period. Moreover, it is difficult to scientifically measure potential and cost (marginal cost of energy savings) and to eliminate the human interference factors.

In consideration of the present situation, we can explore the use of a dual-track system to allocate the energy-saving targets and allow for energy-saving trade quotas among regions. Since industrial enterprises consume the greatest amounts of energy, allocating quotas to the local governments is suboptimal due to the current management framework. Otherwise, mandatory and rigid indicators may lead to high costs and low efficiencies.

1.5.5 China's Energy Flow Analysis in 2008

In terms of the supply structure of primary energy, the structure of final consumption, and the distribution of energy consumption by end use category, China is far behind the developed countries because of differences in its resource endowments and development stage. Figure 1.25 is a graph of energy flows in China in 2008 based on an energy balance sheet (calorific value calculations), including processes like energy production, imports and exports, processing and manufacturing, final consumption, as well as the three structures mentioned above.

The China's total energy supply in 2008 was 2,463,508.8 thousand tce (calorific value calculation). Of this amount, foreign imports was 9.9 %, losses during processing and manufacturing were 670,711.2 thousand tce, losses during transportation and storage were 32,091.0 thousand tons, and final energy consumption was 2,072,349.5 thousand tons. In terms of final consumption, industry amounted to 70.3 %; transportation, storage, and post and telecommunications amounted to 10.3 %; and urban and rural household consumption was 6.5 and 4.1 %, respectively. In 2008, the energy consumption of industry in the OECD countries accounted for 23.0 % while that for residential was 19.2 % (excluding private transportation). As China is still in the process of industrialization, the ratio of industrial energy consumption will remain high for a long time, so there is some downward prospect.

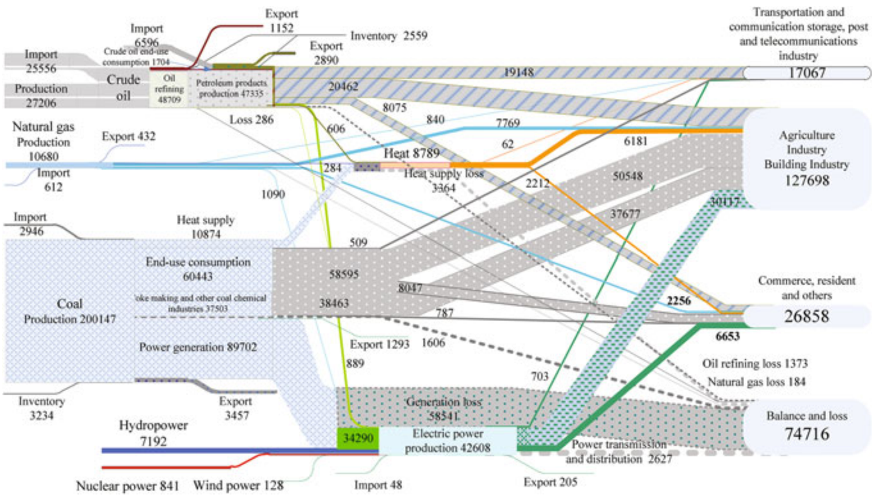

Fig. 1.25 Graph of energy flows in China (2008). (1) According to calorific value calculations; (2) the refueling of Chinese ships and airplanes abroad is included in imports. The refueling of foreign ships and airplanes in China is included in exports. Unit: 10^4 tce

Since 1980, the ratio of energy consumption for coal to the total has generally been in a downward trend, from 63.6 % in the beginning to 28.8 % in 2008 while the use of coal for electricity generation has increased from 20.7 to 48.1 %, and the use of coal for processing and manufacturing took up 71.2 %. In 2008, the supply of raw coal in China was 2749.55 million tons, out of which 1325.17 million tons was used for thermal power generation, 145.40 million tons for heat supply, 572.37 million tons for cleaning and screening, 56.16 million tons for coking, 12.272 million tons for gas generators, 1.75 million tons for coal product processing, and 702.93 million tons for final consumption (out of which 76.08 million tons was for household consumption). The decline in the proportion of coal is good in terms of the desire to use clean energy like electricity and to give way to energy scale, intensification and specialization, improve the efficiency of using coal, and protect the environment by cutting the carbon dioxide emissions. However, the reduced proportion still falls greatly behind that of the developed countries, which also have some downward prospects. In OECD countries, approximately 72 % of the coal was used to generate electricity, 12 % was used for final consumption, and only 1 % was used for household consumption. China used to be a net exporter of coal, but as a result of increasing domestic demand and adjustments to trade policy, net exports were 5.09 million tons in 2008 and it became a net importer of coal in 2009.

China is also a country that produces and consumes coke. There were 56.16 million tons of raw coal, 357.53 million tons of washed coal, and 0.9728 million tons of others that were used for coking. With an efficiency of 97.75 %, the country produced 320.32 million tons of coke, 61.3 billion cubic meters of coke oven gas, 6.42 million tons of other coke chemicals, and 0.56 billion cube meters of other coal gas. China used to export a lot of coke, which represented 60 % of the world total. However, exports declined substantially, becoming 12.21 million tons in 2008. China also produces a lot of steel. In 2009, the production of steel was 696.26 million tons, out of which 85 % was sustained by coke production. Hence, as the speed of steel consumption slows down, there will also be a similar trend in the need for coke.

In 2008, China produced 354,998 tons of crude oil, 34,095 tons of which went to oil refining with an efficiency of 97.17 %, producing 63.47 million tons of gasoline, 11.59 million tons of kerosene, 134.09 million tons of diesel oil, 17.37 million tons of fuel oil, 19.15 million tons of liquefied petroleum gas, 10.96 million tons of refinery dry gas, and 70.68 million tons of other petroleum products. Among the consumption of final products, industry and transportation were the most at 38.0 and 37.8 %, respectively, while household consumption (including private transportation) was 8.4 %. These proportions differed from the developed countries. As for the OECD countries, as much as 63 % was used for transportation (including private transportation) in 2008. As the consumption level in China is increasing, the number of private cars is increasing and so is the proportional consumption of residential transportation. In 2008, 3.48 million tons of fuel oil was used to generate electricity, accounting for 10.7 %, which is a decrease compared with previous years' data. This result is mainly because of the notable improvements in China's electricity supply in 2007.

In China, although natural gas has a lower relative position in China, its consumption is growing quickly. Under the present circumstances of serious climate change and safety problems, striving to develop natural gas resources is both effective and practical. The supply of natural gas was 81.7 billion cubic meters in 2008, making up 3.9 % of the total energy supply (calorific value calculation), whereas the figure was 23.4 % in the OECD countries. In that year, 8.2 billion cubic meters of natural gas were used to generate electricity, 2.14 billion cubic meters to supply heat, and 68.97 billion cubic meters for final consumption, among which 41.68 billion cubic meters was used for industry (10.42 billion cubic meters for raw materials) and 17.01 billion cubic meters for residential consumption (mainly urban residents). As natural gas is low in carbon, clean, and of high quality, enhancing its proportion in total energy consumption is essential to cutting carbon emissions and improving the environment. On December 5, 2009, China began to import natural gas through the China–Asia pipeline, which is connected to the second line of the West–East Natural Gas Transmission Project (designed to transport 30 billion cubic meters per year). In the first half of 2009, the project had already transported 1.7 billion cubic meters. Now in China, there are plans for three oil and gas pipelines that are generally complete: northwest (China–Asia), southwest (China–Burma), and northeast (China–Russia). In the OECD countries, natural gas consumption amounts to nearly 20 % of total consumption of fuel for power generation. Restricted by resource endowments, natural gas is not suitable for generating electricity extensively, but it is necessary to use it for peak production.

There is still a lot of opportunity to optimize the Chinese energy structure. Specifically, renewable resources and natural gas can contribute to its energy supply structure. Greater efficiency in transforming coal into electricity and a higher ratio of electricity in final energy consumption will help improve the energy consumption structure, its efficiency, and the environment. An appropriate industrial structure of low-energy consumption will help optimize the distribution structure.

1.6 Challenges and Reactions of China's Energy Development

1.6.1 Huge Energy Demand with Considerable Uncertainty

Restricted by factors like the stage of social development, a large population, and the inertia effect of the modes of economic development, the growth rate of energy demand in China will stay at a high level in the future. China, the world's most populous developing country, is in the process of industrialization and urbanization and undergoing rapid development. If the average annual energy consumption grows at the rate of 4 % during the 2010–2030 period, the total energy consumption will be close to 7 billion tons of coal equivalent in 2030 (coal equivalent calculation). Even though the per capita energy consumption of China in the future equals that of Japan, which currently has high energy efficiency, the annual energy demand will exceed 8.5 billion tons of coal equivalent (calculated using a population of 1.45 billion). If it equals the average level of that in the United States, the annual energy demand will exceed 16 billion tons of coal equivalent. Consequently, the enormous prospects of greater energy demand have posed a serious challenge to China's future economic and social development. However, the situation of the uncertain demand for energy also provides us with great opportunities to improve energy efficiency.

1.6.2 Insufficient Per Capita Energy Resources, Especially High-Quality Ones

At the end of 2007, the proven recoverable reserves of coal, petroleum, and natural gas were 87 tons per capita, 1.86 tons per capita, and 2270 cubic meters per capita, respectively, representing 69, 7.5, and 8.3 % of the world's average, respectively. Hydropower resources that can be developed were 1900 kilowatts per hour per capita, equivalent to 74 % of the world's average (WEC 2009; World Bank 2009). Moreover, the energy resources in China have an extremely uneven distribution, with a great shortage of quality resources. Without significant technological change or the discovery of large-scale reserves, it will become increasingly difficult to meet the economic and social development needs in the future, as a result of low per capita energy resources, particularly oil and gas reserves. According to data from CEI (2010) and our calculations, as shown in Fig. 1.26, China became a net

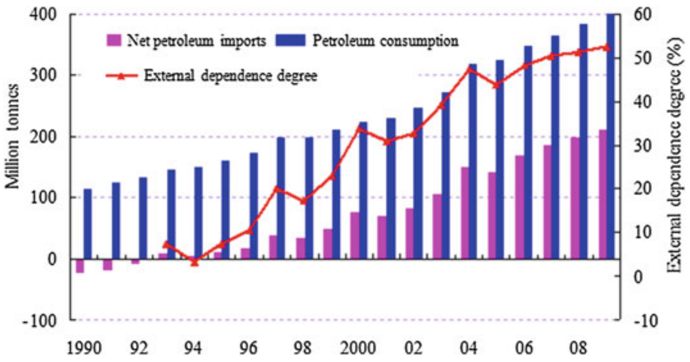

Fig. 1.26 China's net petroleum imports and degree of external dependence (1990–2009). *Data sources* CEI (2010) and authors' calculations

petroleum importer after 1993 and since 1997, the energy self-sufficiency rate in China became less than 100 %. Moreover, since 2000, the net imports of petroleum increased sharply, amounting to 211 million tons, and the degree of external dependence has been rapidly rising, reaching 53 %. In addition, the gradual decrease in energy self-efficiency and the rapid increase in net petroleum imports will affect our national security.

1.6.3 New Challenges Facing Energy Development Due to Global Climate Change

China is one of the few major energy consumers in the world that is coal-dominated, with coal consumption accounting for around 70 % of its total energy consumption (coal equivalent calculation). Consequently, large-scale mining and emissions have brought about serious problems of environmental pollution. China is the world's largest producer of sulfur dioxide emissions, at 23.21 million tons in 2008, and those for soot and industrial dust were 9.02 and 5.85 million tons, respectively, in the same year (MEP 2010).

1.6.4 Global Climate Change Has Brought About New Energy Challenges

China is also a major producer of carbon dioxide with a rapid growth in emissions. Although there are no specific greenhouse gas reduction obligations at present, the worsening of global climate change issues and the growing emissions of greenhouse gas in China will result in greater efforts to mitigate carbon emissions in the future. Since the Industrial Revolution, the largest amount of the global accumulation of greenhouse gases was discharged by the developed countries and the per capita emissions of China are currently only about 35 % of those in the OECD countries. Even though the cost of reducing greenhouse gas emissions is high, developed countries have already completed the process of industrialization and they have had almost no pressure to reduce their emissions of greenhouse gases during that process. However, China is in the process of industrialization, so it has to not only support its economic development and social progress but also cope with the new challenges posed by global climate change simultaneously.

1.6.5 An Important and Effective Way of Facing Challenges: Improving Energy Efficiency

The energy issue has evolved into one of the major issues affecting overall economic and social development. Energy conservation together with a significant improvement in energy efficiency is an extremely important and effective way for China to cope with the aforementioned energy challenges. At an international level, there are already many organizations and experts who have suggested that saving energy represents the world's fifth largest energy source and that this action parallels the production of coal, oil, natural gas, and nuclear energy. WEC (2006) opined that the improvement potential of global energy efficiency is tremendously important and exploitable. The IEA (2006, 2007) has stated that the cheapest, most efficient, and environment-friendly method to meet energy needs relates to the technology of improving energy efficiency and that this should be the top priority among all the various energy technologies. In addition, the three main objectives of energy policy were the security of supply, environmental protection, and economic growth, so improving energy efficiency was "the most important first step" to achieve these three goals. Energy Technology Perspectives 2010 (IEA 2010a), published in May 2010, clearly pointed out that the carbon reduction potential caused by improving energy efficiency was larger than the de-carbonization potential of the electricity sector, which is the largest source for de-carbonization, and that energy efficiency was the primary means to reduce emissions in the short run.

Although energy conservation efforts in China have made great advancements, in essence, energy efficiency is still low. Whether reflected in such aspects as energy extraction, processing, conversion, storage, final consumption and recycling, or economic structure, or whether embodied in the allocation of energy resources or the use of energy inputs, there is a big gap in terms of energy efficiency between China, which has a large potential for improvement, and other developed countries. For instance, industries—particularly energy-intensive industries—make up a high proportion of total production while the share of the tertiary industry is low. The energy consumption level of products such as building materials, nonferrous metals, and thermal power for the advanced developed countries is much higher than that for China. The phenomenon of wasting energy is serious in terms of the low secondary utilization of energy and the low recovery rate related to coal resources. Moreover, energy prices are far from settled and energy-saving incentives are ineffective to name just a few. In fact, some of them are objective reasons that cannot be overcome. In view of national regulations and policies, energy efficiency and energy conservation issues have garnered more attention, and resource conservation has become standard national policy. For example, the first item of the basic content of China's energy strategy is giving priority to thrift. Concerning the importance of issues on energy efficiency, more systematic research will be carried out concerning this topic.

References

BP (2010) World energy statistical review 2010. BP, London
CEI (2010) CEInet statistics database. China Economic Information Network
China Electricity Council (2010) National power industry statistics bulletin list in 2009
Department of Agriculture (2007) National Rural Biogas Project Construction Plan (2006–2010)
Department of Comprehensive Statistics of National Bureau of Statistics (2010) China statistical data compilation 1949–2008. China Statistics Press, Beijing
GWEC (2009) Global installed wind power capacity 2007/2008. Global Wind Energy Council (GWEC), Brussels
GWEC (2010) Global installed wind power capacity 2008/2009. Global Wind Energy Council (GWEC), Brussels
IEA (2006) Energy technology perspectives: scenarios and strategies to 2050. International Energy Agency (IEA), Paris
IEA (2007) Tracking industrial energy efficiency and CO_2 emissions. In: Support of the G8 plan of action. International Energy Agency (IEA), Paris
IEA (2008) World energy statistics and balances (2008 edition). International Energy Agency (IEA), Paris
IEA (2009a) Coal information (2009 edition). International Energy Agency (IEA), Paris
IEA (2009b) Key world energy statistics 2009. International Energy Agency (IEA), Paris
IEA (2009c) World energy outlook 2009. International Energy Agency (IEA), Paris
IEA (2009d) World energy statistics and balances (2009 edition). International Energy Agency (IEA), Paris
IEA (2010a) Energy technology perspectives 2010. International Energy Agency (IEA), Paris
IEA (2010b) Oil market report (12 March). International Energy Agency (IEA), Paris
IHS Herold (2010) Global upstream M&A review 2010. Houston
Liao H, Wei Y-M (2010) The energy structure change characteristics and revelation in group of seven (G7) and BRICs. Energy China 32(2):22–25, 46
MEP (2010) Environmental statistical communiqué of China. Ministry of Environmental Protection of China
National Bureau of Statistics (2009) National statistics database
National Bureau of Statistics (2010a) China statistical abstract 2010. China Statistics Press, Beijing
National Bureau of Statistics (2010b) National statistics database
National Development and Reform Commission (2010) Responsibility evaluation results of regional energy saving target in 2009
National Energy Administration (2010) Energy economy in 2009 and the outlook for 2010
REN21 (2010) Renewables global status report 2009 update. Renewable Energy Policy Network for the 21st Century (REN21), Paris

UN (2010) The millennium development goals report 2010. New York
WEC (2006) WEC statement 2006: energy efficiencies: pipe-dream or reality? World Energy Council (WEC), London
WEC (2009) Survey of energy resources interim update 2009. World Energy Council (WEC), London
Wen JB (2009) Speech at the leader's meeting of Copenhagen climate change conference
World Bank (2009) World development indicators 2009. World Bank, Washington DC
World Bank (2010a) Global economic prospect 2010. World Bank, Washington DC
World Bank (2010b) World development indicators 2010. World Bank, Washington DC

Chapter 2
Relationship Between Energy Efficiency and the Economic System: Measuring Energy Efficiency

In recent years, more and more attention has been paid to the problems of energy efficiency and energy savings. There has been substantial academic research on energy efficiency and most of this research has been beneficial. However, there are still some problems or obstacles about the research methods and objectives to be resolved: (1) The lack of awareness and understanding of energy efficiency leads to an improper use of energy data and energy efficiency indicators, which will probably lead to biased judgments and evaluations; (2) the confusion between the goals of energy research and ways to reach them, including the exogenous and endogenous factors as well as the analyses and results lead us to simply set our goals as "reducing energy consumption" and "decreasing energy consumption per unit of output." If so, then in the long term, from an integrated perspective, energy efficiency will not be improved. Instead, there will be losses in other aspects of the economy and society; and (3) the lack of attention toward basic theories, assumptions, and relationships and the advantages and disadvantages of various indicators of energy efficiency leads to a casual use of the energy efficiency indicators, which will bias our judgments and evaluations.

According to the above phenomena, this chapter will discuss the following questions (Liao and Wei 2010b; Wei and Liao 2010):

- What is the meaning of energy efficiency?
- What is the relationship between energy efficiency and the economic system?
- What indicators of energy efficiency exist now? What are their basic theories and the scope of their applications?
- According to economic theory, can we provide some new indicators and ways to measure energy efficiency?

Y.-M. Wei and H. Liao, *Energy Economics: Energy Efficiency in China*,
DOI 10.1007/978-3-319-44631-8_2

2.1 Reconsideration of Energy Efficiency and Its Relation to the Economic System

2.1.1 Understanding Energy Efficiency

"Efficiency" usually refers to the rationing of output to input. The World Energy Council (WEC 2006) pointed out that energy efficiency is the rationing of energy service output to energy input. In practice, we sometimes use relative efficiency to compare different subjects horizontally or to compare a subject with itself in different time periods. Sometimes, we also use the rationing of the target consumption quantity and the actual consumption quantity. The closer the ration is to one, the more efficient it is. Improving energy efficiency is to use as little inputs as possible to gain the largest quantity of service outputs. The general understanding of the definition of energy efficiency has reached a consensus nowadays. But the real sense of the meaning of energy efficiency is still in doubt.

Energy efficiency is not an isolated measurement. It has a close relationship with the economy, society, environment, technology, and many other domains. Sometimes, simply trying to reduce energy consumption or decrease energy consumption per unit of output may lead to a decrease in energy in the short term using a limited perspective, but the energy efficiency is not improved actually from the long and integrated perspective. This approach could even lead to losses in other aspects of the economy and society. Because of the different understandings of economic efficiency, arguments like the Rebound effect and Jevons paradox have taken place. Papers were published in some famous magazines, such as *Science* (Cherfas 1991; Madlener and Alcott 2009; Sorrell et al. 2004).

Energy is not only an important necessity but also a kind of strategic materials. Chemical resources are non-renewable. The utilization of fossil fuels can result in environmental problems, the destruction of the ecology, changes in climate, and other kinds of public problems. Thus, we should use the cost–benefit principle, the ensure-supply principle, and the sustainable utilization principle to solve our energy problems. The concept of energy efficiency focuses on the contribution made by the consumed energy toward the development of society as a whole. In the different phases of a developing community, the people have different levels of understanding about their individual contributions:

(1) In a macro view, the meaning of energy efficiency is not confined to thermodynamics and engineering technologies. Instead, it includes the economy, society and environment, including sustainable development. From the producer's viewpoint, the producer's goal is to gain benefits and use energy effectively in his own way. From the consumer's viewpoint, the consumer often uses energy by considering its cost and efficiency, even though his habits and education are very important factors in terms of energy demand. The government also has its responsibility to develop strategies according to the

various functions of different energies and the relationship between different energies.

(2) Even though some regular energy efficiency indexes may not show it, the improvement of energy efficiency can be seen from the improvement of equipment and many other aspects. Some energy-consuming activities give people a more satisfactory service despite the cost of consuming lots of energy. Nevertheless, such activities are considered efficient. For example, an airplane flight can cost more than travel by ship over equal distances, but this does not mean that a plane is relatively less efficient. In this case, we mean that a plane travels much faster than a ship. Several ways can help us increase energy efficiency. We can reduce the burning of fossil fuels by reducing the weight of a plane. By installing windows with double-paned glass in place of single-paned glass, one can reduce the electricity used in air-conditioning. Using lower-cost plastic to substitute for higher-cost iron products is another good way to use energy more efficiently. All of the above activities are seen to improve energy efficiency, even though they cannot be included in the energy efficiency index.

(3) Although some activities do not bring about changes in the output of some products, they contribute to sustainable development. This is one kind of energy efficiency improvement. One of the basic reasons for us to improve energy efficiency is the scarcity of natural resources. Most of the energy we use today is fossil fuels, which have a limited storage infrastructure. If the technologies allow us to use solar energy freely, the problems about energy scarcity will no longer exist. If we can use solar energy instead of fossil fuels, the negative effect on the environment will be reduced. In this way, energy efficiency will be improved, but this improvement will not show up in the regular index.

2.1.2 Measuring Energy Efficiency

The energy efficiency index plays an important role in formulating and analyzing policy strategies. The level of energy efficiency cannot cover all the information related to energy efficiency. In practice, we use a one-dimensional index to describe energy for the sake of convenience. Even though it cannot include all aspects of energy, such an index is acceptable as long as it covers most information and does not include significant mistakes. But sometimes, this index is unacceptable because there are different results and conclusions based on different views and evaluation methods or indexes, especially when comparing different regions and countries. In many cases, we use energy consumption per unit of output and energy consumption per unit of added value to calculate the consumption levels and derive a statistical view. The information we get using this approach is rather narrow, so it should not be used to make effective decisions. Therefore, using the wrong index may lead to inappropriate responses and regulations, which are discussed more extensively in publications like *Science* (Larrick and Soll 2008).

(1) All energy efficiency measuring indexes have certain assumptions. Each of these indexes has its advantages, disadvantages, and applicable fields. Simply from a mathematical view, the definition of energy efficiency and how to measure it relates to the rationing of service output to energy input. However, both input and output are multidimensional vectors having elements with different qualities. Some service outputs, such as human life, cannot be measured by money. We cannot simply use division to calculate the vectors. If we have to divide them, some measures must be used to calculate the service output and energy input. A common way to do this is the weighted sum of all of the elements. In this process, some loss of information is unavoidable. For example, if we put in n kinds of energy and the sum of the energy inputs is E, we usually use the first law of thermodynamics and a weighting factor λ_i, which is considered as the power of each kind of energy. If we also use the second law of thermodynamics, the value of λ_i will be different. The regular method is as follows:

$$E = \sum_{i=1}^{n} \lambda_i e_i \tag{2.1}$$

Different fields are calculated in different ways. Thus, there are different indexes to measure energy efficiency. Each index is based on certain assumptions. All of them have advantages and limitations. If all of these prerequisites are not true, then there will be relatively great deviations and even greater miscalculations. All of these biases will lead to wrong decisions. In practice, the method we use relies on the accuracy of the obtained information. In recent times, the normal energy efficiency measuring indexes include the following: energy consumption per GDP, the sum of energy consumption, energy consumption per value added, energy consumption per production unit, and energy consumption in the process of production. All of these indexes are based on certain assumptions.

(2) Energy service output includes both beneficial elements (+) and harmful components (−). According to energy efficiency, energy services will not only include useful components (+) but also consider negative components (−). The key to calculating energy services is to balance its contribution to maintain and encourage the sustainability of the economy, society, and environmental systems. Ideally, we can calculate the net energy service output. The concept of service and output varies. Service is a multidimensional vector, even though it is constructed in terms of both production and services, with different internal characteristics. In the case of the available monetary measurement techniques, we usually see the price as the weight of total production. In the macroscopic measurement of a country or region, service output is based on the country's GDP while for a particular industry or department, service output

is based on the total production value or a value-added index. For a specific product, we use a yield index to represent its service output. Because of the different service outputs in different countries, the consumption of energy among countries will be very different, even though the total production value, value added index, or the level of development are the same. In many cases, the service outputs will differ significantly because of the objective constraints.

(3) The energy input is heterogeneous. Various energies cannot be substituted with alternative energies. From the perspective of energy input, the energy efficiency in terms of size and advantage also depends on how to measure the amount of energy inputs. For the same energy-service quality, we can also have different structures of energy input. Similarly, in terms of energy use per unit of production, the quantity of energy consumption will be different if one uses coal versus natural gas. In the production of hydropower and other renewable energy resources, we sometimes use the heat (caloric) method as the conversion coefficient, and we sometimes use the electric power generation method. Moreover, various types of energy cannot be replaced completely. In the accounting of energy input, the scientific method is not only to consider all kinds of energy embodied in energy consumption but also to consider their respective prices and costs, as well as the possible substitution of alternative energies. Otherwise, the energy input data will sometimes be very different, and these differences will affect the results of any research on the energy economic system.

(4) The resource endowments and initial and developmental stages will vary among countries. It is difficult to make an accurate and quantitative comparison of China's energy consumption per unit of GDP with that of the developed countries. At present, the results vary in terms of an international comparison of unit outputs of power consumption. According to the indexes from the World Bank (2009) and IEA (2009), which use the exchange rate method, China's energy consumption per unit of GDP is more than four times that of the United States. In contrast, according to purchasing power parity (PPP), China's consumption is only 70 % higher than that of the United States. Nordhaus (2007), a professor at Yale University, has raised some issues between the 3E modeling data conversion method and the Superlative-PPP method. According to Nordhaus (2007), the resulting data differences are related to the quality of the basic data, caliber of the statistics, quality of the energy and raw material and data availability, and the means by which the data were acquired.

2.1.3 Energy Efficiency and the Economic System

Most of the direct use of energy is commercial. Energy efficiency is reflected in all aspects of the energy value chain, including energy extraction, processing, conversion, storage, final demand, and recycling, as well as in terms of national production, distribution, trade, and consumption. Thus, to study a country or region's energy problems, we should first study how energy fits into the economic system. Energy saving should also consider both the costs and benefits, as pointed out by Joskow and Marron (1993a, b), whereby the different ways to save energy have different costs. A reduction in the output per unit does not necessarily equal to a reduction in the cost and an increase in efficiency. Some regions spend a great deal of money on various environment-friendly and efficient buildings to maintain a positive image, but such gains may not make up for their losses.

2.1.3.1 Structural Heterogeneity and Element Substitution

Structural heterogeneity includes the economic structure (industry, demand, disposition of income, region, urban and rural, ownership and price, and the structure of various factors or elements, especially energy). Energy is heterogeneous because the different types of energy cannot be substituted for one another. Factor substitution includes elasticity of capital, labor, and land, as well as the elasticities of oil, coal, electricity, and other energy.

The study of energy economics will result in a number of combined heterogeneous structures and factors, and a resulting loss in information, if we only study the total data without a structural analysis of how the components are integrated. Because of this loss, the reliability of the scientific research will be reduced. In recent times, product and energy structural differences in the measurement of energy efficiency have gradually caught the attention of the public, but the heterogeneity of the economic structure is still not reflected in the measurements.

Structural heterogeneity and factor substitution have some common connections, but they are also distinct. Both emphasize the internal system of the various components of the differences. The former is mainly from a statistical accounting perspective while the latter is mainly from an economic perspective. The following Fig. 2.1 shows their relationship:

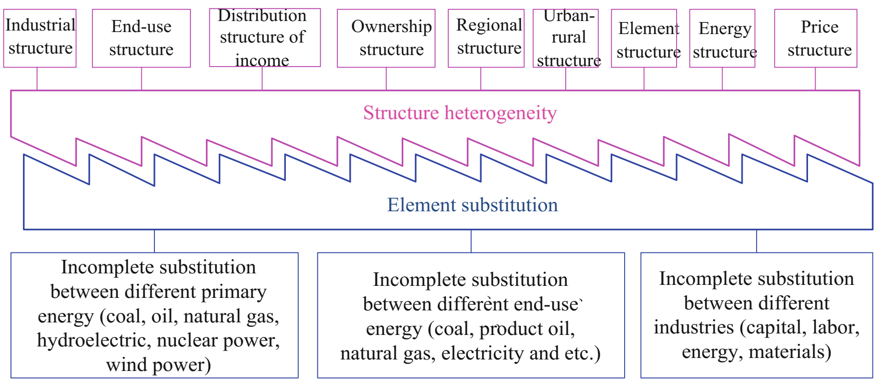

Fig. 2.1 Structural heterogeneity and factor substitution, including energy

2.1.3.2 Factor Production Rates and Energy Efficiency

For a very long time, manufacturing has been the major energy-consuming sector. Energy is an important element in terms of production. Economic growth cannot exist without energy inputs. The source of economic growth mainly includes the factors of investment (capital, labor, and resources) and the growth of total factor productivity (including human capital accumulation). Therefore, in terms of growth of total factor productivity, we can formulate an analytical structure of energy efficiency and an economic system to analyze energy efficiency and the energy structure, economic growth and economic structure, and technological development. This will enable an in-depth discussion about the influence of energy efficiency.

In the determination of the sources of economic growth and the theoretical discussion of the quality of economic growth, most of us use the product–capital–labor model, which means that the total growth of the combined factors (the common speed of technological development) equals the economic growth rate minus the weighted capital (or capital service) and labor (or labor service) investment growth rates. Such business accounting seldom considers the industrial structure. The inputs only include capital and labor, with the implicit assumption that the natural resources or energy for economic growth have no effect. Economic growth is essentially an evolving process by sector. Without a sector analysis, it is difficult to explain why and how the process happened (Rostow 1959). A study of energy requirements and energy efficiency cannot be separated from those of the total economy and, in particular, when studying the economic structure because the total represents the overall picture, but the structure represents the specific content.

To discuss the relationship between economic growth and energy efficiency in terms of both technological development and product structure, we use the method to calculate the sector production rate (Jorgenson et al. 1987; Jorgenson and Stiroh 2000), like Y = KLEM (output = capital, labor, energy, materials[1]), which is different from the calculation of the total production rate. For a certain production sector i in a certain period, to gain an output, Y_i, we need to include four factors: capital (K_i), labor (L_i), various energy sources $\{e_{i1}, e_{i2}, \ldots, e_{is}\}$ $\eta_c < 1$, and raw materials (M_i). The function is:

$$Y_i = A_i \cdot f_i(K_i, L_i, M_i, e_{i1}, e_{i2}, \ldots, e_{is} \tag{2.2}$$

A_i refers to the technology level of sector i. The technological improvement here is Hicks neutral. The function f_i meets the regularity condition and homogeneous conditions. We can see that the energy and other elements are separate.

$$\exists X_i \in \{K_i, L_i, M_i\},$$

[1]Material means intermediate inputs except energy, including intermediate production and services.

$$\frac{(\partial f_i/\partial e_{iu})/(\partial f_i/\partial e_{iv})}{\partial X_i} = 0 \quad (u \neq v) \tag{2.3}$$

Thus, the production function can be expressed as:

$$Y_i = A_i \cdot f_i(K_i, L_i, E_i, M_i) \tag{2.4}$$

Within the above function,

$$E_i = g_i(e_{i1}, e_{i2}, \ldots, e_{is}) \tag{2.5}$$

If we assume that

$$Q_i = f_i(K_i, L_i, E_i, M_i) \tag{2.6}$$

the function g_i also meets the regularity condition. Make the total differential to Eq. 2.6

$$dQ_i = \sum_{X_i=K_i,L_i,E_i,M_i} \frac{\partial f_i}{\partial X_i} dX_i = \sum_{X_i=K_i,L_i,E_i,M_i} \lambda p_i \cdot dX_i \tag{2.7}$$

where g_i is the price of X_i and λ is a Lagrangian multiplier:

$$\lambda = \frac{\partial f_i/\partial X_i}{p_i} = \frac{Q_i}{\sum_{X_i=K_i,L_i,E_i,M_i} p_i X_i} \tag{2.8}$$

The Eq. 2.7 can be changed to:

$$Q_i \cdot d \ln Q_i = \sum_{X_i=K_i,L_i,E_i,M_i} \lambda p_i X_i \cdot d \ln X_i \tag{2.9}$$

Based on Eqs. 2.8 and 2.9,

$$d \ln Q_i = \sum_{X_i=K_i,L_i,E_i,M_i} \frac{p_i X_i}{\sum_{X_i=K_i,L_i,E_i,M_i} p_i X_i} \cdot d \ln X_i \tag{2.10}$$

Suppose that $\alpha_{K_i} = \frac{p_i K_i}{\sum_{X_i=K_i,L_i,E_i,M_i} p_i X_i}$, $\alpha_{L_i} = \frac{p_i L_i}{\sum_{X_i=K_i,L_i,E_i,M_i} p_i X_i}$, $\alpha_{E_i} = \frac{p_i E_i}{\sum_{X_i=K_i,L_i,E_i,M_i} p_i X_i}$, $\alpha_{M_i} = \frac{p_i M_i}{\sum_{X_i=K_i,L_i,E_i,M_i} p_i X_i}$. Obviously, these four equations represent the cost component of the various factors.

According to Eqs. 2.4 and 2.10, we can get the function of the production sector i:

$$\begin{aligned} d\ln Y_i &= d\ln A_i + d\ln Q_i \\ &= d\ln A_i + \alpha_{K_i} d\ln K_i + \alpha_{L_i} d\ln L_i + \alpha_{E_i} d\ln E_i + \alpha_{M_i} d\ln M_i \end{aligned} \tag{2.11}$$

where $\alpha_{K_i} d\ln K_i$, $\alpha_{L_i} d\ln L_i$, $\alpha_{E_i} d\ln E_i$, and $\alpha_{M_i} d\ln M_i$ refer to the contributions of capital, labor, energy, and raw materials, respectively. $d\ln A_i$ represents the contribution of the total production growth rates of the factors for sector i to the sector's total output. The growth rate of the total factors for the whole economy, $d\ln A_i$, equals the sum of the various factors.

$$d\ln A = \sum_i w_i \cdot d\ln A_i \tag{2.12}$$

With the weight expressed as $w_i = \frac{P_i Y_i}{PV}$,[2] $P_i Y_i$ is the total value of a particular sector. PV is the total increase, which means the total GDP of a country. To improve the growth rate of a country's economy, the growth rate of the sum total of the underlying factors needs to increase.

For a specific production sector, whether or not it can reduce the consumption per unit depends on whether we can use the growth rate of the total factors of production, including the capital and material increases, as efficiently as possible to replace the energy increase. However, whether we can achieve this goal depends on the relative price changes of energy and the other factors, as well as the alternative elasticities, including those of the production sector itself. If the price of energy rises and prices of other factors decrease, the output per unit of energy consumption will decline; that is, the savings in energy come first over the savings in capital, labor, and raw materials.

For example, during the production of iron, we need to consume both the ore and energy, which can be substituted by each other. To produce a ton of the same quality of pig iron, the energy consumption is different when using high-grade ore versus poor-grade ore. If the price of iron ore is increasing, the iron and steel companies may be inclined to consume more energy and less ore. If the price of iron ore is decreasing, the iron and steel companies may be inclined to consume less energy and more ore. Not only is energy a substitute for the other factors, but the various types of energy have different elasticities among them; that is, the alternative elasticities among different types of energy are different. According to the concepts of energy efficiency, it is difficult to support a particular method's advantages and disadvantages.

Within a certain period of development, each alternative's use of energy, capital, raw materials, and other production factors is relatively weak because of technical and economic constraints. For a number of categories, the relationship between

[2]The sum of these weights is generally greater than 1 (because the sum of total output is greater than the total value added).

energy and capital is complementary. Capital deepening is the process of rapid growth in energy consumption. Thus, for a specific category i, in order to decrease its energy demand per unit of output, we should rely more on the growth rate of output and $d \ln A_i$, instead of $d \ln E_i$. This also represents an improvement in economic quality. A category's total rate of increase includes not only the speed of progress for science and technology but also softer factors like the efficiency of resource allocation to improve the situation, the positions of various government functions and so on.

At different development stages, the total factor productivity growth rate for different sectors may have a different bias. For example, to produce the same quality and quantity of a product, a company can save a lot of labor and raw materials by introducing a new kind of production method. However, this change may save little energy or even no energy at all. In this case, the relevant policy incentives can encourage enterprises to strengthen their energy conservation technologies and research and development efforts. In the process of industrialization, technical progress is often a type of energy consumption (Liao 2008).

According to Eq. 2.12, for the entire national economy to improve the macro energy efficiency, it is not enough to only depend on the total factor productivity growth rate ($d \ln A_i$). We must also rely on the adjustment of the industrial structure (i.e., adjusting $w_i w_i$). We must reduce the consumption of the energy-intensive sectors and decrease the proportion of energy-intensive sectors in the national economy. Broadly speaking, the adjustment of the industrial structure includes the overall structural adjustment, including the individual product structural adjustments. For example, one can reduce the energy consumption in the iron and steel sector by decreasing the ratio of steel and iron and increasing the ratio of continuous casting and the steel rolling rate. As a result of its relevance to industry, such an adjustment is often progressively and dynamically pursued. Moreover, it has a close relationship with final demand. In the long term, the structure of residential consumption plays a key role. Such consumption has significantly affected how industrial structure has evolved. In the upgrade stage of the residential consumption structure, houses, automobiles, household appliances, and other high energy consumer goods begin to enter the household. This entry may drive the industrial structure in the direction of energy-intensive development (Wei et al. 2006). Comparative advantage and the foreign trade structure have a guiding role on the evolution of the industrial structure. The income distribution structure will also affect the final demand structure, thereby affecting the industrial structure (Liao 2008).

The mathematical analysis is mainly in the neoclassical economic analysis framework. The growth rate of energy consumption is mainly based on the economic growth rate and growth quality. The quality of economic growth can be generalized as the various factors of production inputs (and their combinations) that promote economic growth. The quality of economic growth is not only present in the contribution of the total factors to the growth of the economy but also in the contribution to the growth in output from the production and industry structures, and from the relationships between the different industries. The quality of economic growth is closely related to the hard features, such as the specific technical equipment and management level, as well as the soft features, such as the legal and economic systems, and the fixed agendas of the various government functions.

2.1.4 Energy Efficiency and Energy Conservation

In many documents, including government policy documents, "improving energy efficiency" and "conservation of energy" are used interchangeably. They do not distinguish between the two definitions. The newly revised Energy Conservation Law points out that saving energy is the means of strengthening energy management. We should take feasible and reasonable measures that the environment can bear, including all linkages of energy production and energy consumption, to reduce consumption, losses, waste, and pollution emissions and to make effective and reasonable utilizations of energy. In the book entitled *Basic Terms in Energy*, edited by the National Energy Base and Standard Technical Management Committee (1991), energy conservation refers to the scientific management and use of advanced technology in each link for improving the utilization of energy. The two definitions of energy conservation include both narrow and broad definitions. "The Encyclopedia of Energy" in Gibbons et al. (2004), published by Elsevier Company, defines "energy conservation" as "on the basis of not decreasing the quality of life, a scientific method used to reduce energy consumption through technology and policy changes."

(1) In general, energy improvement equals energy conservation, but they are different. The meaning of energy efficiency is broader. Energy efficiency focuses more on energy services while energy conservation focuses on the reduction in energy consumption. Energy efficiency focuses on the meaning within energy economics, such as social benefits, while energy conservation focuses on the real and physical meanings.[3] In addition, energy efficiency focuses on systems analysis while energy conservation sometimes focuses on local (regional) analysis. Though the two concepts have some differences in terms of practical issues, we often use them without any strict limitations. In the energy economics model or the energy macroeconomic policy target, energy-saving often means the fall in unit GDP energy consumption rather than a specific reduction in absolute volume. In the specific energy model construct, the target function is different, so there are different results. The function is also related to the model system of boundary demarcations. Energy conservation without consideration of the cost is unacceptable.

[3]This is consistent with profit maximization and cost minimization in the new classical economic theory. But due to reasons such as information asymmetry and incentives, they are incompatible and sometimes inconsistent.

We assume that "improving energy efficiency" is better than "increasing energy efficiency." The language of management science and systems science describes the former as a multi-objective programming problem and the latter as a single-objective programming problem.

(2) In general, we usually transform the multi-objective problem into a single objective problem as a result of the problems with various data sources and measurements. If we consider energy heterogeneity and incomplete alternative to calculate the amount of energy use, the result will support our decision function. Energy efficiency is not a static or short-term objective, and it should be considered from a dynamic or long-term perspective. Therefore, to agree with the meaning associated with the scientific language, the improvement of energy efficiency becomes a dynamic programming problem.

2.2 Indicators and Measurement of Energy Efficiency

The energy consumption's connotation is that the contributions made by consumed energy to maintain and promote the social economy and environmental system should be through sustainable development. Energy efficiency is usually expressed as the ratio of energy service output to energy input. But there are different methods to determine the quantity of energy input and service output in different industries. Hence, we have different indexes. The current or historical levels of energy efficiency are objective calculations, but it is not usually possible to use an index that completely covers all aspects of the information that should be included in energy efficiency (because of limited information and data availability). In practice, and for the sake of convenience, we use a one-dimensional index to describe energy efficiency. This index cannot cover all of the information, but most information can be included in the index, at least partially, to meet our needs so that it can be considered an acceptable index. Sometimes, a particular index cannot give us the information we need, so we need to create other indexes. Each index is based on certain assumptions (e.g., homogeneity and comprehensive alternative assumptions) with certain advantages and disadvantages. If these assumptions cannot meet our demands, they may result in great inaccuracies in terms of our understanding and measurement of energy, resulting in errors in calculations, biased judgments, and bad decisions.

This chapter will conduct a systematic analysis of the energy efficiency measuring indexes, outline the problems associated with these indexes and reach various conclusions. We discuss the basic theories and hypotheses, relationships and limitations, and some things to consider when using these indexes. The seven indexes are energy macro-efficiency, energy physical efficiency, energy thermodynamics efficiency, energy value efficiency, energy allocation efficiency, energy utilization efficiency, and energy economic efficiency.

2.2.1 Energy Macro-efficiency

Nowadays, we usually use energy consumption per unit of GDP, a macro index called “energy intensity,” to measure country, regional, or industrial energy efficiency levels. We define its reciprocal as macro-efficiency, e_m (energy macro-efficiency). The lower the increase in energy consumption per unit of GDP, the higher is the energy macro-efficiency. The output of energy is expressed by the outputs from economic activities. Energy input is expressed as the consumption of primary energy. The increased value per unit of power consumption is related to the development stage, economic structure, technical level, energy price, social culture, geographical location, climate conditions, resources, and other factors. During the past two centuries, the UK, United States, and other developed countries have shown a rise in per unit GDP energy consumption during the process of industrialization that peaked before falling. The later a country entered the industrial state in the industrialization process, the lower was the unit value of GDP energy consumption. Sometimes, there was no increase in consumption per unit of GDP, which was mainly a result of the progress of technology and the advantage of being a backward country that arrived much later in the process of industrialization.

In certain documents, we sometimes define the reciprocal of the energy consumption per unit of GDP as the “energy production rate.” Strictly speaking, the two definitions are of very different calibers. When calculating energy consumption per unit of GDP, we include the direct use of energy by households. However, when calculating the energy production rate from the viewpoint of calculating GDP in the production method, the direct use of a household’s energy will be excluded (as in the difference between GDP per capita and labor productivity, the former refers to the entire population while the latter calculation only includes the number of laborers). In China, since the direct energy use of households is low, the difference between the energy production rate and the reciprocal of the energy consumption per unit of GDP is very small. In the horizontal and vertical comparison between regions, a significant bias will usually not happen.

When big differences do not occur in the energy input structure, the measurement of energy efficiency based on energy consumption per unit of GDP is easy and there is relatively less probability that this measurement of efficiency will change. When the energy input structure changes a lot, incomplete substitutes among various energies may lead to some bias in the results. (For more information, please refer to Liao 2008 and Liao and Wei 2010a.) However, macro energy efficiency relating to economic growth mainly relies on such underlying assumptions relating to energy consumption and technological progress. In fact, economic development relies on other factors, which have different types of substitutes. Hence, the energy macro-efficiency index is a partial measure that does not consider the substitute elasticity between energy and other alternatives. Discussion about these concepts can be found in Liao (2008). To overcome or reduce these limitations, we should sometimes use other energy efficiency indicators. From a microeconomic viewpoint, it is inappropriate for some documents to regard energy efficiency as “energy economic efficiency" (the concept and measure of the efficiency of the energy economy will be given later).

From the view of the production method used to calculate GDP, GDP is the total increase in value for all fields of activity and the associated increase in energy consumption. Each industry can be further decomposed to the product level. Hence, as long as we can secure the data, the macro energy-efficiency changes will inevitably be decomposed into the changes in the industrial structure and the changes in the energy efficiency, which are commonly referred to as the structure share and the efficiency share. The Divisia index method is by far the best index decomposition method. The Törnqvist index method is a processing form that uses discrete approximations. Diewert (1976) pointed out that for the linear logarithmic homogeneous function and unit cost function, Törnqvist's quantity index and price index are accurate. According to the definition, considering only the energy used in production, energy macro-efficiency meets the assumption of the linear homogeneous function. Even though the Divisia index can decompose macro-efficiency into different levels, it is just a decomposition of the total data from top to bottom to a large degree. The information we gain is limited; thus, the support for the resulting decisions is weak. The goals relating to energy conservation are known worldwide and include two parts: reducing the proportion of the energy-intensive industries (or the proportion of the energy-intensive products) and increasing the speed of improvements in technology. However, the product structure and technology levels are largely endogenous. They represent the results, not the reasons behind the actions.

When comparing nations, the value of the economic products must be transformed into the same currency because of the international monetary system. The normal methods are MER, PPP, and so on. Ideally, PPP is the most suitable method, but it is hard to calculate (of course, there are also problems with the method itself). The results are not completely accurate as the method is not comprehensive and uses broad data. For example, according to the exchange rate method, China's energy consumption per unit of GDP in 2007 was 5.78 tons per 1000 USD, which is 3.8 times that of the OECD countries. According to the World Bank's data, it was only 2.75 tons per 1000 USD, which is 1.7 times that of the OECD countries. Comparing the data from the World Bank (2009) and IEA (2009) with our data, we can see that under two different exchange rate methods, developed countries are located near the 45° line, but China, India, and other developing countries are far from the line. Figure 2.2 describes the energy consumption per unit of GDP in the BRICs and some OECD countries.

Nordhaus (2007), a professor from Yale University, introduced the Superlative-PPP method, which falls between the two methods mentioned above, to model the global energy, economic, and environmental problems aimed at solving the problems in the PPP method, which is based on exchange rates and world prices. In December 2007, the World Bank published a study to compare the results of the International Comparison Program (ICP) across the world and it subsequently modified the PPP coefficients. Even though the data are more exact through such modifications, the PPP calculations for China continue to have some problems

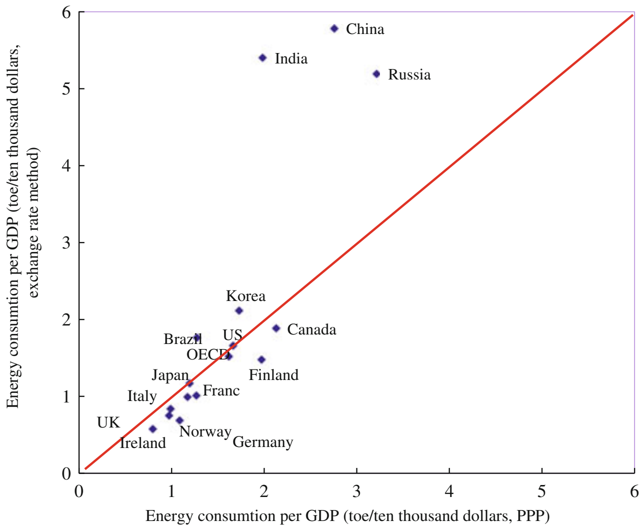

Fig. 2.2 The energy consumption per unit of GDP in the BRICs and some OECD countries (2007). *Data sources* World Bank (2009), IEA (2009) and authors' calculations

because of some constraints between the theoretical method and the basic data. The degree of market integration in the developed countries is relatively high and the conversion system is accurate when one uses the PPP data to compare the unit GDP energy consumption in the developed countries; thus, the results are relatively accurate and reliable. However, when using the World Bank's PPP data for China to compare its energy consumption per unit of GDP with the developed countries, the ordinal number is relatively meaningful, but the cardinal number is meaningless.

2.2.2 Energy Physical Efficiency

We usually define the energy consumption per unit of product and the energy consumption during the production process as the physical energy efficiency, e_p (energy physical efficiency); some examples include the total energy consumption per ton of steel production, comparable energy consumption per ton of steel, tons of steel consumption, power consumption, energy consumption per ton of cement, etc. It is common practice that the technical indicators do not include the magnitudes of value. This approach has been widely introduced and will not be discussed any further here. Energy efficiency is a suitable measure of comparison between the different production structures of an enterprise. It responds to the micro-economy and technical equipment level of management. At present, many companies and industry associations in China promote the "benchmark" based on energy consumption per unit of product. In the "Tenth Five-Year Plan" period,

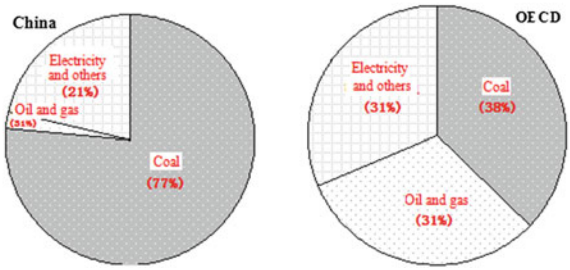

Fig. 2.3 Energy structure of the iron and steel sector in China and the OECD countries (2007). *Data sources* IEA (2009c) and authors' calculations

China's energy macro-efficiency appeared to decline (using the coal consumption method). But the main energy consumption's physical efficiency continued to decrease, especially in products requiring raw materials such as iron, steel, cement, and glass.

We need a unified measure when we compare energy consumption per product and energy consumption during the production process between countries and enterprises. For example, we still have a long way to go to catch up with the developed countries in terms of calculating the energy consumption per ton of product. The items included in the energy consumption calculations for Japan include solid fuel, gas fuel, electricity, oxygen, and steam, but the items for China also include compressed air, nitrogen, water, and other mediums besides those in Japan. If the blast furnace uses blowers, then the air flow is included when calculating total energy consumption. According to the thermal equivalent method, the unit energy consumption is high for our main products. In addition to our use of technical equipment, other important reasons for this result include the quality of raw materials and the energy consumption structure. If one does not take these factors into account, then one may overestimate China's energy-saving potential. For example, using the thermal equivalent method, energy consumption per unit of product in China's iron and steel industry is higher than that in the developed countries, where the iron ore includes a higher proportion of poor quality ore. Figure 2.3 shows that China's energy consumption structure in the iron and steel industry in 2007 was 77 % coal while that for the developed countries was only 38 % coal. When using the physical efficiency indicators, the energy inputs sometimes vary relatively more, so the conclusions will be different than those found when using the heat equivalent, coal consumption method. One also needs to consider various alternatives that do not completely replace the original energy sources.

2.2.3 Energy Thermodynamics Efficiency

Energy physical efficiency refers to e_d (energy thermodynamics efficiency). The calculation is based on the theory of thermodynamics. Based on different steps in energy flow, it can usually be divided into energy exploitation, processing, storage and transportation, and terminal utility efficiency. The physics of energy efficiency can also be classified as the first law of thermodynamics efficiency and the second law of thermodynamics efficiency. According to the first law of thermodynamics, energy physical efficiency in China has improved a lot during the past twenty years. In 2005, the energy extraction efficiency, intermediate linkages utilization efficiency, and final use efficiency were 33.2, 68.4, and 53.9 %, respectively. The total physical efficiency was 13 %. According to data from the NBS-DE and NBS-DCS, China's power stations' and power plants' heating efficiency was 40.24 % and their coking efficiency was 97.78 %. The efficiency of coking oil was 97.17 %.

According to the second law of thermodynamics, energy conversion has a direction. According to the theorem of the Carnot cycle, a cycle consists of two isothermal processes and two adiabatic processes known as the Carnot cycle efficiency: $\eta_c = (T_1 - T_2)/T_1$. In practice, since the absolute temperature of a true high-temperature, T_1, heat source cannot be infinite, the absolute temperature of a low-temperature, T_2, heat source cannot be zero. Hence, $\eta_c < 1$. Heat cannot be completely converted into mechanical work. Based on the second law of thermodynamics, the calculated thermal efficiency can be even lower. The energy physical effects' calculation is more complex and also involves more knowledge of thermodynamics, which has been introduced already. We will not discuss this in depth.

2.2.4 Energy Value Efficiency

Due to the heterogeneity of the various types of energy or quality differences, the same equivalent of the effects will be different. In some areas or businesses, although their energy consumption is low, they consume mostly high-quality energy (such as natural gas, a net transfer of electricity), whose cost is not low. To calculate the total number, we can use the thermal equivalent coefficient as the weight of the various types of energy and we can also calculate the total in terms of weighted prices. In this way, we can calculate the energy efficiency value, e_v. If the energy used in the production of outputs can also be measured by value, we can compare the energy efficiency value and the other indexes for different countries and find out the reasons why they are different (e.g., low energy prices and different energy structures); that is, why differences exist between the macro-efficiency and physical efficiency of different countries. In the calculations of the magnitude of energy consumption in different countries or regions in terms of value, one needs to be consistent in terms of what is included in the calculations (e.g., in terms of VAT, output taxes, transportation costs, etc.).When we compare energy efficiency values vertically, the value of energy efficiency will be different because of changes in energy prices. Therefore, the value of energy efficiency is more suitable in terms of a horizontal comparison. The advantage of the value of energy efficiency approach is that it is not influenced by the international comparisons of countries in terms of the exchange rate or PPP.

Using comparable input–output tables based on the 48 sectors defined by OECD and major developing countries, we calculated the values of energy efficiency in

Table 2.1 A comparison of the efficiency of the energy value in China and the major developed countries (2005)

Country	Energy consumption	GDP	Energy value efficiency		Energy macro-efficiency	
			Absolute ratio	Indexation	Absolute ratio	Indexation
France	1.62	17.26	10.63	1.10	6.75	1.27
Germany	2.34	22.45	9.58	0.99	7.28	1.37
Italy	1.51	14.30	9.50	0.98	8.78	1.66
Japan	552	4996	9.05	0.94	7.30	1.38
US	12.9	124.2	9.66	1.00	5.30	1.00
China	37.45	186.26	4.97	0.51	3.11	0.59

Energy value efficiency is calculated according to the input-output table for the OECD in 2009. Value is in domestic currency units (100 billion). Energy macro-efficiency data is from the World Bank. The index used is US = 1

China and the major industrialized countries in 2005 (data for the UK and Canada are missing). To make accurate comparisons, energy consumption amounts are calculated at producer prices (final energy demand). The results are outlined in Table 2.1. We can see that the U.S. energy macro-efficiency is obviously lower than that of four other countries, but the country's energy efficiency is not less than that of other countries; it is sometimes even higher. This result is partly because the various final energy prices are generally lower than those in other countries (Table 2.2), regardless of the estimations using either the exchange rate or PPP methods. In 2005, China's energy value efficiency was 50 % of that for the developed countries.

From the dynamic point of view, the value of energy efficiency can also be defined as the ratio of the service output for the full life cycle of the equipment to energy costs. For example, the price of energy-saving lamps may be very high, but in the long term, we save more energy and actually improve the energy value by using them (part of this substitution achieves equivalence by replacing energy with capital).

2.2.5 Energy Allocation Efficiency

The energy allocation index mentioned above is based on some common experiences, statistical knowledge or thermodynamic knowledge. The index relies little on knowledge of the economy. Now we use mathematical economic theory to determine the index of energy allocation efficiency, e_a. Allocation of resources, which is an economic system and price mechanism problem, has a close relationship with the ability to motivate users in terms of the importance of reducing energy consumption. Energy allocation efficiency, e_a, is related to various material prices. It reflects the ways to reduce the cost of materials by changing their combinations under a certain relative price system.

Table 2.2 Final energy prices in major developed countries, including tax (2005)

Country	Unleaded gasoline (USD/l)		Residential natural gas consumption (USD/m^3)		Industrial electricity (USD/kWh)		Industrial light fuel oil (USD/kl)		Commercial motor vehicle diesel (USD/l)	
Currency conversion method	Exchange rate	PPP	Exchange rate	PPP	Exchange rate	PPP	Exchange rate	PPP	Exchange rate	PPP
France	1.442	1.257	0.55	0.48	0.050	0.043	563.3	491.1	1.062	0.926
Germany	1.519	1.411	–	–	0.084	0.078	559.7	519.7	1.143	1.061
Italy	1.515	1.408	0.77	0.71	0.174	0.162	1084.4	1007.3	1.147	1.066
Japan	1.131	0.961	1.16	0.99	0.123	0.104	439.5	373.5	0.745	0.633
US	0.626	0.626	0.46	0.46	0.057	0.057	427.7	427.7	0.633	0.633
China	0.47	–	0.22	–	0.073	–	–	–	–	–

France, Germany, Italy and US is #95 unleaded gasoline, Japan is regular unleaded gasoline. China's price is the average price for 36 cities and industrial electricity represents the large-industry price

To directly analyze the resource allocation, we use a two-dimensional yield line analysis method. As shown in Fig. 2.4, OYY' is the equality yield line, which means the minimum combination of the two elements, e and x, to produce the same amount of y with the technology level unchanged.

The combination of the factors of production is based on the principle of cost savings or the quest for profit. In a given production level, y, and element price levels (p_e, p_x), the minimum cost of the elements is:

$$\begin{aligned}&\text{Theobjectivefunction: } \min ep_e + xp_x \\ &\text{Constrains : } y = f(e, x)\end{aligned} \tag{2.13}$$

whereby you can obtain the best combination of elements, $R(e^*, x^*)$. The yield on a tangent, AA', is the point R, where

$$\frac{f_e'(e^*, x^*)}{f_x'(e^*, x^*)} = -\frac{p_e}{p_x} \tag{2.14}$$

The relative price level of the various factors of production is a key factor of the determinants in the investment structure. If the actual relative price level, p_e/p_x, is distorted, the price is relatively low. Thus, the slope of the tangential line is relatively low and a corporation will choose point R to be the combination of production elements. The slope of the straight line, CC', reflects the relative price level of the elements in response to both opportunity costs. That is the tangent with the isoquant at point R. For the whole society, the best combination of elements of such a configuration should be at R′. The potential savings in energy is $\Delta e = OE_1 - OE_2 = E_2E_1$. This is due to factor price distortions and a low factor allocation. We define the total element allocations as

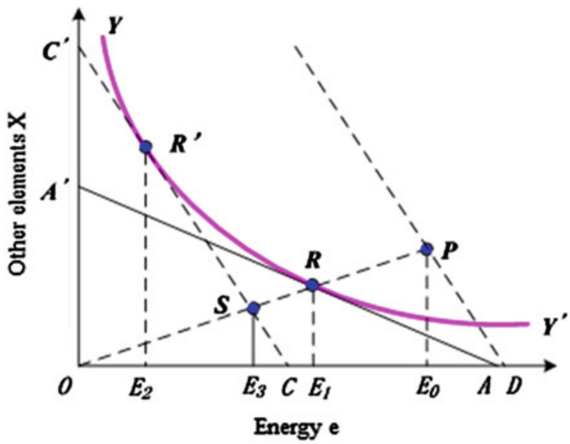

Fig. 2.4 Energy allocation efficiency diagram

$$E_a = \frac{|OS|}{|OR|} \tag{2.15}$$

When the three points coincide, the allocation efficiency is at its highest. If the energy price level is low, in which the slope, AA′, is too small, then the investment income that the enterprise uses to save energy and improve energy efficiency is not as good as for other aspects of the investment gains. Thus, an enterprise's selection of raw materials for its infrastructure, technological transformation, and equipment renewals will not be too much to improve energy efficiency in the first place. For example, the iron and steel enterprises need to consume iron ore and energy in the production process. If energy prices are low (below the shadow price), then the businesses will tend to minimize their cost by purchasing low-grade iron ore and consuming multiple types of energy; that is, replacing some of the iron ore with energy. Due to the low cost of energy for the entire national economy, the country's industrial structure may trend towards energy-intensive development. Within the specific industry, this response could lead to higher energy inputs with a higher proportion of energy consumption related to households and a lower relative proportion related to other inputs. A reasonable price level will include not only energy extraction, processing, conversion, and storage costs but also the costs of non-renewable resources and pollution controls pertaining to the environment (most of the present energy consumption is non-renewable fossil fuels). The above analysis is based on two dimensions using a two-factor analysis. However, the analysis of many elements in multidimensional space can also reach the same conclusion.

The energy allocation efficiency, e_a, is an essential part of total element allocation efficiency, E_a. The analysis of the energy allocation efficiency is as follows:

$$e_a = \frac{|OE_2|}{|OE_1|} \tag{2.16}$$

In calculating the energy allocation efficiency, the first step is to calculate the energy economic efficiency. This calculation will be presented later in this chapter.

Energy is a scarce resource. The energy configuration in various sectors and enterprises can affect energy efficiency. A planned economy is one way to allocate resources, but overall, its efficiency is very low and the choice of point R is likely to deviate from R', resulting in price distortions (or prices without markets and excess supply).

The main reasons are that (1) planners often do not have sufficient capacity to optimize the allocation of resources. There are various levels of technology and production conditions for the different government departments in different regions. Optimum planning is often difficult in terms of a timely response to various types of resource supplies and an accurate estimate of the shadow prices of the various inputs. (2) A planned economy is not a very effective incentive mechanism. In fact, the producers or planners can calculate the shadow prices and the optimal mix of resources, but they cannot determine their own corresponding incomes. Therefore, in a planned economy, it is difficult to incentivize the producers and planners to make this effort. (3) A planned economy is not an efficient individual institution. The mistakes made cannot be attributed to any one person. Hence, nobody will be accountable and pay for their mistakes. (4) If planners are not subject to regulations, they may artificially distort resource allocations. In China's past, low energy prices, energy resource allocation, and scheduling were mostly controlled by the country's planning department, where energy resources tended to be assigned to the energy-intensive heavy industrial sectors. This partly caused an imbalance between light and heavy industries that determined the allocation of energy resources, leading to a low level of macro-efficiency.

An open market is the best way to allocate resources. In a market environment where the full responsibilities of property rights are clear and there is complete information and a sound legal system, producers and consumers will adjust their structures of production and consumption according to various inputs and prices to gain more profits. To increase energy services and energy efficiency, we should maximize the usage values of every kind of energy and reasonably allocate energy to various economic and daily activities. Energy resources should be distributed wisely to maximize the value of energy use, which is a requirement of increasing energy services and improving energy efficiency. Because of incomplete information and technological uncertainty, the allocation of resources (0P in Fig. 2.4) cannot totally depend on the market, even though the market is the source of our struggle to use it effectively.

2.2.6 Energy Utilization Efficiency

Energy as a factor of production is usually included with the other elements of capital, labor, and raw materials involved in the production process. The energy efficiency of factor allocation is based on various combinations of the elements and it is used to calculate the optimal combination of various elements. The e_u (energy utilization efficiency) can reduce the element requirements under the established element combinations. Assuming that we need the same quality and quantity of products, the combinations of capital, labor, raw materials, and energy can vary, as shown in Fig. 2.4, where R represents the point of actual production when it is connected with the origin, OR, and also intersects with the equal product quantity line at point P. Referring to Farrell (1957) and Färe et al. (1985), they use E_u to represent $\frac{|OR|}{|OP|}$ when studying production efficiency. When points P and R are coincident, the efficiency of the total elements is one, which is the highest value. The element use efficiency is one when the point lies on the isoquant. In most of the mathematical economics literature, the elements' utilization efficiency is also called their technical efficiency, radial efficiency, or Farrell efficiency (it can also be described by the production possibilities curve). In practice, with the same quantity and quality of inputs, the output may differ. This difference will be represented in the aspects of the elements' utility efficiency. To calculate this efficiency, we need to construct an isoquant, which is a smooth curve that cannot be obtained directly. It is usually estimated based on the envelope formed by the production unit (strictly speaking, this differs from the potential isoquant). We usually use the production unit of an envelope to estimate the isoquant. The method is called data envelopment analysis (DEA). If the utilization efficiency of the energy factor is defined as the "total factor energy efficiency," this meaning is somewhat appropriate (and generally does not cause any misunderstanding).

The energy elements' utility efficiency, e_u, is defined as the ratio of the OR and OP projected distances in the energy axis, E, or $\frac{|OE_1|}{|OE_0|}$. We can use DEA to calculate the isoquant YY' and the energy elements' utility efficiency. Based on the experience of Hu and Wang (2006), the calculation is represented as follows: $X_i = (N, E)$, where E represents the energy and N represent the other elements (Fig. 2.5).

Thus, the energy utility efficiency is

$$e_u = \frac{|OE_{12}|}{|OE_0|} = \frac{\left|\frac{OR_1}{OP}\right| \cdot |OE_0| - |R_1R_2|}{|OE_0|} = \frac{\theta \cdot |OE_0| - |R_1R_2|}{|OE_0|} \tag{2.17}$$

$|OE_0|$ is the compression mapping along the E axis of $|OP|$. θ is the relative value of DEA.

For any production unit O, the relative valid value of DEA is θ_0. We can calculate the value through linear programming. $|R_1R_2|$ is a linear programming relaxation variable.

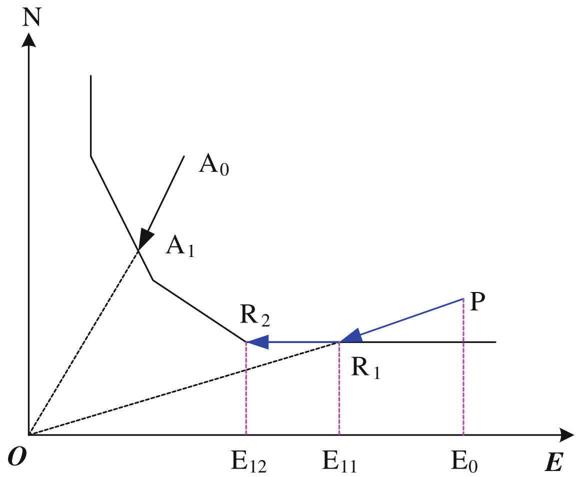

Fig. 2.5 Diagram of energy utility efficiency

The objective function: $min\,\theta_o$

$$\text{Constraints:} \begin{cases} \sum_{i=1}^{n} \lambda_i X_i + S_i^+ = \theta X_o \\ \sum_{i=1}^{n} \lambda_i Y_i - S_i^- = Y_o \\ \lambda_i \geq 0,\ i = 1, \ldots, n \end{cases} \tag{2.18}$$

Within Eq. 2.18 above, S_i^+ and S_i^- are the input and output relaxation variables. Liao (2008) applied this method to calculate China's energy elements' efficiency in different industries in 2006 by considering the differences in the quality of similar elements and comparing them with the biased macro-energy efficiency indicators. Studies have shown that in terms of the 2006 macroeconomic efficiency of China's industrial sector, the energy utility differences were greater than those in terms of energy inputs (by using the coefficient of variation measure) (see Chap. 7). This finding is mainly because the latter calculation considers capital and labor's alternative elasticities. If we also consider the differences among regions, the differences of energy utility efficiency among the regions are much smaller.

In theory, the DEA method is very suitable for the calculation of energy utility efficiency. However, the DEA is very sensitive to the basic data. If the evaluation of an object determines that its value lies in an extreme position, it may have a great impact on the production frontier and thereby affect the results of the other objects being measured. Hence, when we use the DEA method, we need to do some basic analysis of the data included in the object's input index. According to some studies, their calculations show that the energy utility efficiency of a region can be less than 5 % of that for another region. In addition, in terms of production for a certain industry or corporation, energy, capital, labor, and raw materials form the combined input elements. In the process of any calculations, the absence of any one in these four items will influence the results. For a country or region, energy is both an input and an output. Hence, we must define the inputs and outputs clearly so that they are not misrepresented in the calculations.

2.2.7 Energy Economic Efficiency

Energy economic efficiency, e_e, is part of the energy cost efficiency, E_e. Energy economic efficiency equals an element's utility efficiency multiplied by its allocation efficiency.

$$E_e = \frac{|OR|}{|OP|} \cdot \frac{|OS|}{|OR|} = \frac{|OS|}{|OP|} \tag{2.19}$$

Energy economic efficiency, e_e, is the result of the entire project on the axis e of OP. Under the situation without relaxation (i.e., Fig. 2.4, in which the medium production line, YY', is the implicit function P_0's first derivative of P_0):

$$e_e = \frac{|OE_2|}{|OE_0|} = \frac{|OE_2|}{|OE_1|} \cdot \frac{|OE_1|}{|OE_0|} = e_a \cdot e_u \tag{2.20}$$

Before we calculate the energy economic efficiency, we should first determine the energy efficiency (the former is part of the latter). Färe et al. (1985) and others have raised the idea that we can use DEA to solve the problem of energy efficiency. The objective function is to minimize the total cost. For any given unit O, under the conditions of given capital, labor, raw materials, and the energy vector P_0, the potential minimum cost can be calculated through the following linear progression:

$$\begin{aligned} &\text{The objective funtion: } min\, P_o\tilde{X}_o \\ &\text{Constraints: } \begin{cases} \sum_{i=1}^{n} \lambda_i X_i \le \tilde{X}_o \\ \sum_{i=1}^{n} \lambda_i Y_i \ge Y_o \\ \lambda_i \ge 0,\ i = 1, \ldots, n \end{cases} \end{aligned} \tag{2.21}$$

$\tilde{X}_o$ represents the objective needs of every elements; that is, when the output is Y_0, to meet the lowest total cost, all elements have the minimum quantities. Y_0 is the output.

Economy efficiency:

$$E_e = \frac{P_o\tilde{X}_o}{P_oX_o} = \frac{|OS|}{|OP|} = \frac{|OC|}{|OD|} \tag{2.22}$$

Equation 2.20 can be deduced by the line CC′, which is parallel to the line through point P. CC′ is the isocost line. The cost of production at point R′ is |OC| while the actual cost of production is |OD|. Using DEA to calculate the economic efficiency already exists, so there are no slack variable problems, and no information will be lost. On this basis, we put forward our method of calculating the energy economic efficiency:

Energy Economy efficiency:

$$e_e = \frac{p_e\tilde{E}}{p_eE} \tag{2.23}$$

where P_e is the price of energy. (when only one energy is included, $P_e \in$ P; when several types of energy are included, $P_e \subset$ P) $\tilde{E}$ is the object energy demand. e_e is the ratio of the object energy cost to the actual energy cost. When the input energy is only one type, $e_e = \tilde{E}/E$. It is obvious that when the economic efficiency is

100 %, the energy economic efficiency is 100 %; otherwise, the solution may not be valid. The allocation efficiency of the energy factor is equal to the ratio of the energy efficiency and energy factor utilization efficiency (provided that in calculating the elements' utilization efficiency, the slack variable is 0).

Besides the DEA method without parameters, we can also use the production and cost functions and the regression analysis method to calculate the elements' utility efficiency, energy allocation efficiency, and economic efficiency. The differences between the energy macro-efficiency and energy economic efficiency are the same as those between the labor efficiency and total elements' efficiency (not considering the energy use by households). Energy macro-efficiency has some bias while energy economic efficiency does not. Moreover, the efficiency calculated by the DEA method is a relative concept. An efficiency of one represents the best among the evaluated objects, but it does not mean that it cannot be improved.

The concept or measure of the efficiency of the energy economy actually combines the energy savings and cost. In the development of energy efficiency policies, decision making by government departments is usually based on macro-energy efficiency or physical efficiency. But if the cost is large, resulting in no reduction in costs or no increase in profits, then it is difficult to motivate energy users to take such initiatives. The government needs to set reasonable incentives (such as in the energy and environment tax systems) for energy users to adopt energy efficiency measures with both cost savings and successful and compatible incentives. This practice will improve not only the macro-energy efficiency but also the efficiency of the energy economy.

2.3 Summary

Energy efficiency is not only a scientific and technical issue but it is also an economic, social, environmental, and development issue. It has highly complex, comprehensive, and systematic problems. China is in the rapid development stage of industrialization and urbanization, so energy resources per capita are relatively inadequate and energy consumption is huge. Higher growth without more certainty in terms of production and consumption will lead to greater environmental pollution. Moreover, carbon dioxide emissions caused by energy development and its uses are increasing and becoming prominent problems. Maintaining rapid economic development, improving the quality of life and energy efficiency, and slowing the growth of energy consumption are extremely important goals for China's current and future energy development.

With research on energy efficiency in China continuing to move forward, we can make the results more scientific and practical by discussing the problems in many ways. (1) Considering the relationship between the total energy supply and demand in various regional economies, we need to pay attention to the structural heterogeneity problems, especially the impact of changes in the energy structure. (2) The energy structure can be measured by both its physical quantity and its economic value. If we use the latter, China's consumption is mainly oil rather than coal. (3) Depending on the different issues and data, we can use the estimated energy efficiency indicators to avoid single-indicator information bias. (4) To build a computable general equilibrium model based on a particular measurement method, we should consider the various elements within the energy sector, as well as the other elements, and their variable elasticities of substitution.

The amount of energy consumed contributes toward maintaining or promoting the sustainable development of the total economic, social, and environmental systems. Hence, the goal is to promote economic development and the way to reach this goal is to improve energy efficiency, as the processes cannot be changed. The former is the goal while the latter is the means. Energy is an important element of production, so it is interrelated with the other aspects of the economic system. In terms of the macro economy, we cannot use energy consumption per unit of GDP or the value added per unit of energy consumption as the sole indicators of progress. Energy should be included in a comprehensive survey of the entire economic system, which includes comprehensive inspections of each stage of development, the area's natural endowments and the labor base differences under objective conditions. We should combine the savings in energy, the reduction in costs, and the increase in revenues to avoid "one-size-fits-all" evaluations and conclusions.

Energy macro-efficiency, energy physical efficiency, energy thermodynamics efficiency, energy value efficiency, energy allocation efficiency, energy utilization efficiency, and energy economic efficiency are seven indexes to describe energy efficiency. Each of them has a theoretical base, assumptions, relationships, advantages, and limitations. Any single index cannot completely represent a particular energy efficiency level.

Different indexes have different suitable fields of research, measurement methods, and required data. The most common ones are macro-efficiency and energy thermodynamics. Sometimes, we simply set a goal to reduce energy consumption or reduce energy consumption per unit of output because of confusion between the purposes and means of endogenous and exogenous variables, as well as their causes and results. From the static and local points of view, energy consumption has been reduced. From the long-term and global perspectives, energy efficiency has not improved, and it has even caused loss of other aspects of the economic and social systems. Energy conservation could fall into the "doing more harm than good" category. In practice, we should choose some indexes according to certain situations, with special attention to the heterogeneity of different forms of energy and the alternative calculations of data indicators (Liao 2008).

For a country or region, energy economic efficiency is a relatively ideal index. But we need more accurate data, which is usually hard to obtain (even itself with uncertainties), especially when the index uses data to represent the environmental costs and unsustainable energy prices. No matter what kind of data is used, we need to enhance the data caliber as much as possible for both horizontal and vertical comparisons. Although macro-efficiency has some bias, it is suitable for long-term analyses. In most studies, little attention is paid toward the absolute value of the energy index. We are more concerned about the horizontal and vertical comparisons of energy efficiency, the gap between the energy efficiency of different subjects, and the speed and direction of changes in energy efficiency.

References

Cherfas J (1991) Skeptics, visionaries examine energy saving. Science 251(4990):154–156

Diewert WE (1976) Exact and superlative index numbers. J Econometrics 4(2):115–145

Färe R, Grosskopf S, Lovell CAK (1985) The measurements of efficiency of production (studies in productivity analysis). Kluwer-Nijhoff Publishing, Boston

Farrell MJ (1957) The measurement of productive efficiency. J Roy Stat Soc 120(3):253–290

Gibbons JH, Gwin HL, Cutler JC (2004) Conservation measures for energy. Elsevier, New York

Hu JL, Wang SC (2006) Total-factor energy efficiency of regions in China. Energy Policy 34(17):3206–3217

IEA (2009) Key world energy statistics 2009. International Energy Agency (IEA), Paris

Joskow PL, Marron DB (1993a) The cost of energy efficiency. Science 262(5132):319–321

Joskow PL, Marron DB (1993b) What does utility-subsidized energy efficiency really cost. Science 260(5106):281–370

Jorgenson DW, Stiroh KJ (2000) U.S. economic growth at the industry level. Am Econ Rev 90(2):161–167

Jorgenson DW, Gollop FM, Fraumeni BM (1987) Productivity and U.S. economic growth. Harvard University Press, Cambridge

Larrick RP, Soll JB (2008) The MPG illusion. Science 320(5883):1593–1594

Liao H (2008) Study on econometric model of energy efficiency and its application. Dissertation, Chinese Academy of Sciences

Liao H, Wei Y-M (2010a) China's energy consumption: a perspective from Divisia aggregation approach. Energy 35(1):28–34

Liao H, Wei Y-M (2010b) Energy efficiency and its relationship with economic systems. J Publ Adm 7(1):28–34

Madlener R, Alcott B (2009) Energy rebound and economic growth: a review of the main issues and research needs. Energy 34(3):370–376

Nordhaus W (2007) Alternative measures of output in global economic-environmental models: purchasing power parity or market exchange rates? Energy Econ 29(3):349–372

Rostow WW (1959) The stages of economic growth. Econ Hist Rev 12(1):1–6

Sorrell S, O'Malley E, Schleich J et al (2004) The economics of energy efficiency: barriers to cost-effective investment. Edward Elgar, Northampton, MA

Subcommittee on Energy Terms of National Energy Base and Standards Technical Management Committee (1991) Energy base term. Science Press, Beijing

WEC (2006) WEC statement 2006: energy efficiencies: pipe-dream or reality? World Energy Council (WEC), London

Wei Y-M, Liao H (2010) Seven energy efficiency indicators and their measurement approaches. Chin Soft Sci 1:128–137

Wei Y-M, Liang Q-M, Fan Y et al (2006) A scenario analysis of energy requirements and energy intensity for China's rapidly developing society in the year 2020. Technol Forecast Soc Chang 73(4):405–421

World Bank (2009) World development indicators 2009. World Bank, Washington DC

Chapter 3
Impact of Economic Structural Changes on Energy Macro-efficiency

China is in the process of industrialization and the changes in its industrial structure are relatively rapid. The state of the industrial structure restricts the final demand structure and national income distribution structure. In contrast, the direction and speed of changes in the industrial structure are led by the final demand structure and national income distribution structure. In this chapter, we will use quantitative analysis (methods such as national economic accounting and statistical methods) to analyze the influence of China's industrial structure, end-use structure, and national economic distribution structure on its energy macro-efficiency in a step-by-step fashion from the endogenous to exogenous factors. Further, we will analyze the direct and indirect effects of urbanization on residential energy consumption. We mainly discuss the economic structure and energy macro-efficiency. To be consistent with the current policies in China and some of the popular literature, we adopt energy intensity (energy consumption per unit of GDP and energy consumption per unit of added value) to directly describe these issues. The issues mainly discussed in this chapter are (Liao 2008)

- What is the main effect of the changes in the three largest industrial structures on energy intensity?
- What is the effect of the change in the internal industrial structure on energy intensity?
- What is the effect of the change in the final demand structure on energy intensity?
- How does the national income distribution structure affect energy intensity?
- What are the direct and indirect effects of the urbanization process on residential energy consumption?

Y.-M. Wei and H. Liao, *Energy Economics: Energy Efficiency in China*,
DOI 10.1007/978-3-319-44631-8_3

3.1 Linkages of the Industrial Structure and Energy Intensity

3.1.1 Statistical Description of the Change in Energy Intensity

The energy intensity in China has experienced several considerable fluctuations since 1949. However, it has been consistent with the development of China's economy and society for most of the time. According to the calculations by NBS-DCS (2010), NBS (2010), as well as our calculations, the basis of heavy industry, such as the consumption of energy and raw materials, developed quickly; the proportion of the energy-intensive industries rose; the energy consumption per unit of GDP increased during the first five-year plan, as shown in Fig. 3.1. During the 1959–1960 period, the national economy was badly hurt because of the "great leap forward" and the energy consumption per unit of GDP rose sharply, from 28,800 to 45,500 Yuan/tce.[1] Afterwards, through the processes of adjustment, consolidation, completeness, and improvement of the national economy, the energy consumption per unit of GDP dropped rapidly until 1967. During the 1967–1977 period, the energy consumption per unit of GDP increased once again, which was consistent with the cultural revolution as a whole.[2] After China carried out its reform and opening-up policies in 1978, the energy consumption per unit of GDP continued on a relatively fast downward trend and the cumulative decrease was 70 % during the 1978–2007 period. From 1997 to 1999, the increasing speed of energy consumption slowed down. However, from 2003 to 2006, China's industrialization process accelerated and the growth in total energy consumption was even faster than that of the economy. To stop energy consumption from increasing too fast and energy consumption per unit of GDP from increasing continuously, the central government set a goal in 2006 to reduce energy consumption per unit of GDP by about 20 % during the "Eleventh Five-Year Plan" and took several useful legislative, administrative, and economic measures. The goal was evenly distributed among the provincial and local governments, and it became the reference point in terms of subsequent performance evaluations. With the effort of all parties, the energy consumption per unit of GDP showed a significant decrease during the 2007–2009 period. However, for the purpose of coping with the global financial crisis, the government carried out several influential policies in 2009 to stimulate

---

[1]Coal equivalent calculation at constant prices, Base year = 2005.

[2]If you remove the impact of the "great leap forward," from 1953 to 1977, China's total energy consumption per unit of GDP was steadily rising. The planned economic system is not enough to fully explain the reasoning behind this outcome. Since the first five-year plan and even before that time, China has been engaged in the process of industrialization and its industrial system had begun to gradually form, even though there were many structural problems. According to the experience of the developed countries, the energy consumption per unit of GDP often rises in the early stage of industrialization (the rising amplitude or speed is worth further research).

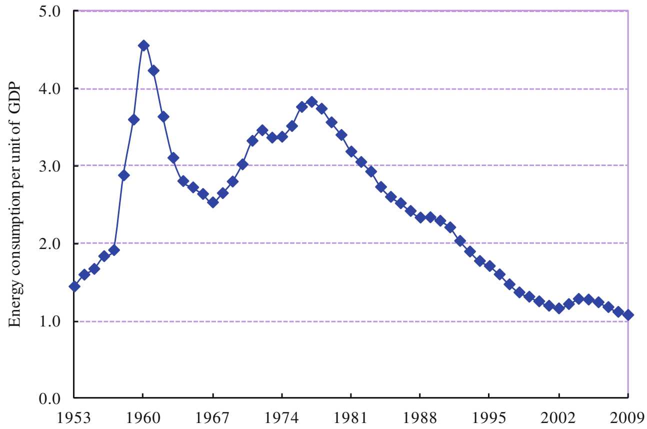

Fig. 3.1 China's energy consumption per unit of GDP (1953–2009). *Data sources*: NBS-DCS (2010), NBS (2010) and authors' calculations

investment. Thus, investment in fixed assets increased rapidly, driving a relatively fast growth in energy consumption. In the first quarter of 2010, the high energy consumption increased even more quickly and the national energy consumption per unit of GDP increased by 3.2 % at the same time. In the first four years of the "Eleventh Five-Year Plan," the global energy consumption per unit of GDP declined cumulatively by 15.6 %. The energy-saving target of the "Eleventh Five-Year Plan" was likely to be realized, but the cost was high.

In all aspects of the national economy, the industrial sector takes an important position. According to the coal equivalent calculation method, the current industrial added value takes up 40 % of GDP and about 72 % of all national energy consumption, as shown in Figs. 3.2 and 3.3 (NBS 2010; NBS-DITS 2000; NBS-DITS and NDRC-BE 2006, 2007; NBS-DE and NBE-DCS 2008, 2009, 2010). In the current phase in China, and from the perspectives of technological energy savings and structural energy savings, the industrial sector is important for saving energy, decreasing consumption, and improving energy efficiency.

According to the experiences of development in recent years, the high growth rate of an economy is often driven by higher industrial growth. According to NBS (2007, 2008a) and our calculations, as shown in Fig. 3.4, when the growth rate of an economy is high (more than 10 % per year), industry often increases faster than the tertiary industry (e.g., the periods of 1993–1997 and 2003–2006). Moreover, the faster the economy increases, the bigger the difference of the added value growth rate between industry and tertiary industry. The relatively faster industry increase often means that the growth in energy demand is relatively faster. When the growth rate of the economy is low (less than 10 % per year), the growth rate of industry and the tertiary industry is basically equal (e.g., the period of 1998–2002). In such circumstances, the growth rate of energy consumption is slower or even negative. Figure 3.5 shows the relationship between the growth rate of the economy and the

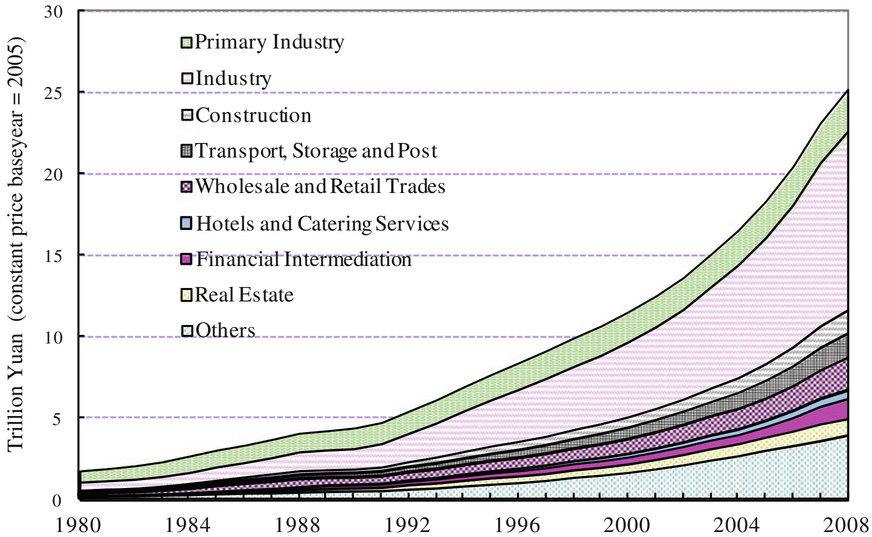

Fig. 3.2 Added value of all industries in China (1980–2008). *Data sources* NBS (2010) and authors' calculations

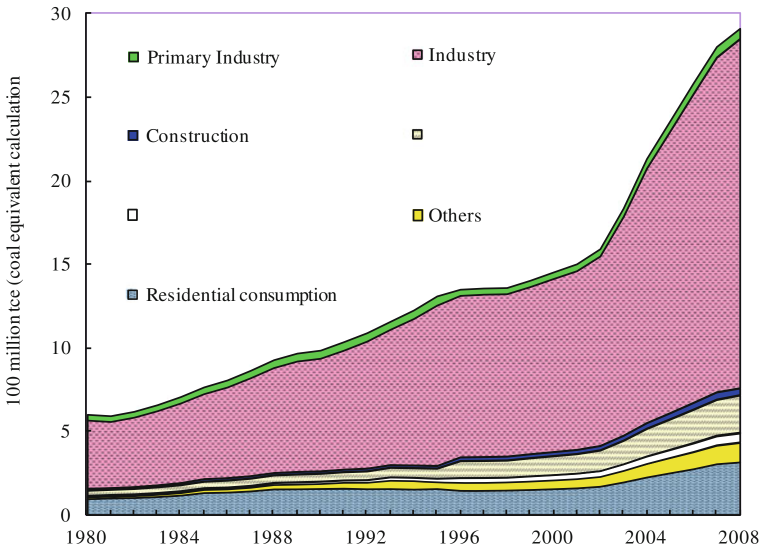

Fig. 3.3 China's industrial energy consumption structure (1980–2008). *Data sources* NBS-DITS (2000), NBS-DITS and NDRC-BE (2006, 2007), NBS-DE and NBE-DCS (2008, 2009) and authors' calculations

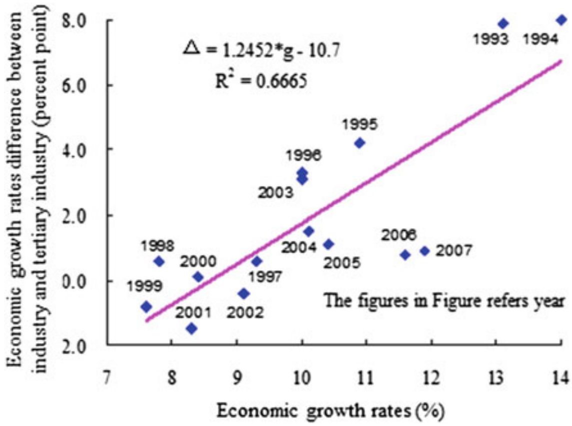

Fig. 3.4 Economic growth rates and the discrepancy between industry and the tertiary industry (1993–2009). *Data sources* NBS (2007, 2008a) and authors' calculations

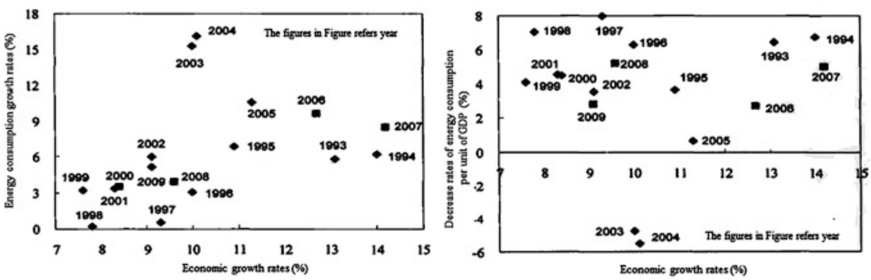

Fig. 3.5 Historical relationships of the energy economic indexes (1997–2009). *Data sources* NBS (2007, 2008a) and authors' calculations

growth rate of energy consumption, and the decline in energy consumption per unit of GDP using the coal consumption method (the conclusion is the same when using the Divisia decomposition method). Since the economic structure is difficult to adjust in a short timeframe, the growth rate of the economy should not be too high to create energy savings (recently, however, it was 10.5 %). In the first half of 2010, China's economy grew by 11.1 % within the same period and the industrial sector grew by 17.6 %. As a result, the energy consumption per unit of GDP rose again compared with the same period in the previous year.

At present, the energy consumption per unit of added value for industry is five times that of the tertiary industry in China. Because of the correlation of different industries and the inertia factor within the economic system, the internal structure of industry is difficult to develop in the non-energy-intensive direction rapidly. The relatively rapid growth of industry often drives the increase in energy demand, so it is difficult to decrease the energy consumption per unit of GDP quickly.

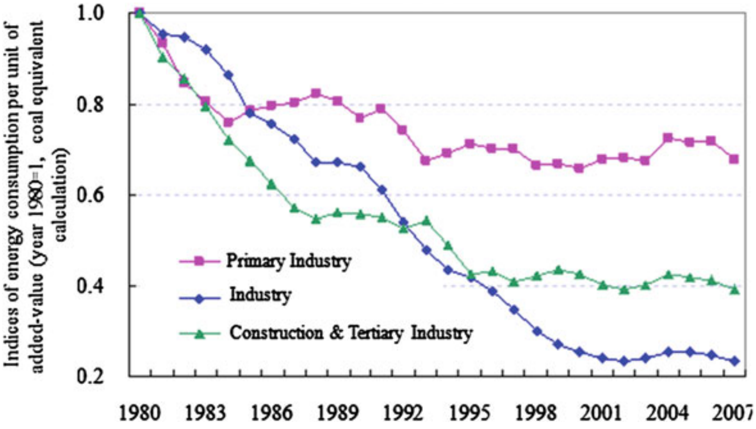

Fig. 3.6 China's energy consumption per unit of added value by industry (1980–2008). *Data sources* NBS (2008a, b) and authors' calculations. Since the National Bureau of Statistics amended the data after 1996 in China's Energy Balance Tables in 2010, but did not amend the data before 2005, the energy consumption data in the sub-sectors show a great fluctuation during the period from 1995 to 1996

Industrialization will be one of the notable features of the Chinese economic and social development in the next twenty years, and it will bring many challenges for saving energy and improving the macro-efficiency of energy.

As shown in Fig. 3.6, the energy consumption per unit of added value in China's industrial sector has declined relatively quickly since 1980, for an accumulated total of 75.3 %. This decline has played an important role in decreasing the national energy consumption per unit of GDP, especially after 1996. The structural change of the three major industries has shown a negative contribution towards energy savings. It was the decline in energy consumption per unit of added value for all industries that made the greatest contribution (including the internal structure, product structure, and technological improvement of all sectors).

3.1.2 *Impacts of Internal Industrial Structural Change on Energy Intensity*

There are many studies of the change in China's energy consumption per unit of GDP or the energy consumption per added value of industrial production from these two dimensions: the industrial structure and the energy consumption per added value by sector. Some of them use the structural decomposition method to study the energy consumption per unit of added value in China's industrial sectors, but there are some problems in data processing. The data standards of the energy economy are not consistent, the prices in different years cannot be compared, and the production is calculated repeatedly. To overcome these problems, we use the added value data in an input–output table in this section and convert the data into comparative prices to calculate the structural effects and the intensity effects of the changes in energy consumption per added value in the industrial sectors during the 1997–2002 period (Liao et al. 2007).[3] The extent of the various decompositions by industry is different, so the results are different. The more detailed that an industry is disaggregated (e.g., to the level of products or enterprises), the closer are the results between the intensity effect and technology improvement effect; however, the requirements for basic data are much higher. In this section, we divide the information on the basis of major industries. For the situation during the 2003–2006 period, the statistical data is mainly descriptive.

3.1.2.1 Fundamental Principles of the Divisia Decomposition Method

In this section, we mainly use the Divisia decomposition method. Suppose that the whole industrial sector is divided into n subclasses (or subsectors) and t stands for the period, where Y_t, E_t, and I_t stand for the added value, energy consumption, and energy consumption per added value of the total industrial sector, respectively. So, $I_t = E_t/Y_t$, where Y_{it}, E_{it}, and I_{it} represent the added value, energy consumption, and sector intensity, respectively,[4] () of subsector i (i = 1, …, n) and $I_{it} = E_{it}/Y_{it}$. S_{it} represents the percentage of the added value of subsector i to the total industrial added value and $S_{it} = Y_{it}/Y_t$. I_{it} reflects the technology level while S_{it} reflects the industrial structure. The change in I_t can be found using factor decomposition according to the forms of relative variation or absolute variation. Ang (1997, 2004, 2005, 2006) and Ang and Zhang (2000) have conducted substantial research in the domain of factor decomposition of energy intensity.

(1) Divisia exponential decomposition method in a relative quantity form
Energy consumption per added value in industrial sector I_t is the weighted average of I_{it}, the energy intensity for all subsectors. The weight is the percentage of the added value of a subsector to the total added value for all industrial sectors.

$$I_t = \frac{E_t}{Y_t} = \frac{\sum_i E_{it}}{Y_t} = \frac{\sum_i Y_{it} \cdot I_{it}}{Y_t} = \sum_i \frac{Y_{it}}{Y_t} \cdot I_{it} = \sum_i S_{it} \cdot I_{it} \tag{3.1}$$

[3] In much of the literature, it is defined as the “efficiency effect” or “technical effect”. The following chapters of this book will include further discussions of this matter.

[4] To find the difference, we use the “sector intensity,” which actually means the energy consumption per added value for that sector.

For both sides of Eq. 3.1, we make a differential on t:

$$\begin{aligned}\dot{I}_t &= \sum_i \dot{S}_{it}\cdot I_{it} + \sum_i S_{it}\cdot \dot{I}_{it} = \sum_i S_{it}\cdot I_{it}\cdot \frac{\dot{S}_{it}}{S_{it}} + \sum_i S_{it}\cdot I_{it}\cdot \frac{\dot{I}_{it}}{I_{it}} \\ &= \sum_i \frac{E_{it}}{Y_t}\cdot \frac{\dot{S}_{it}}{S_{it}} + \sum_i \frac{E_{it}}{Y_t}\cdot \frac{\dot{I}_{it}}{I_{it}} = \sum_i I_t\cdot \frac{E_{it}}{E_t}\cdot \frac{\dot{S}_{it}}{S_{it}} + \sum_i I_t\cdot \frac{E_{it}}{E_t}\cdot \frac{\dot{I}_{it}}{I_{it}}\end{aligned} \tag{3.2}$$

Both sides are divided by I_t:

$$\frac{\dot{I}_{it}}{I_{it}} = \sum_i \frac{E_{it}}{E_t}\cdot \frac{\dot{S}_{it}}{S_{it}} + \sum_i \frac{E_{it}}{E_t}\cdot \frac{\dot{I}_{it}}{I_{it}} \tag{3.3}$$

For both sides, we make the curve integral and get:

$$\int_\Gamma \frac{\dot{I}_t}{I_t} = \int_\Gamma \sum_i \frac{E_{it}}{E_t}\cdot \frac{\dot{S}_{it}}{S_{it}} + \int_\Gamma \sum_i \frac{E_{it}}{E_t}\cdot \frac{\dot{I}_{it}}{I_{it}} \tag{3.4}$$

This is the integral path, representing the curve segment (S_t, I_t) in time interval (0, T). According to Hulten (1973), the curve integral in Eq. 3.4 is unrelated to the integral path under the condition of linear homogeneity (according to the definition of energy consumption per unit of GDP; here, it fits the condition). Thus,

$$\ln\left(\frac{I_T}{I_0}\right) = \int_0^T \sum_i \frac{E_{it}}{E_t}\cdot \frac{\dot{S}_{it}}{S_{it}}\cdot dt + \int_0^T \sum_i \frac{E_{it}}{E_t}\cdot \frac{\dot{I}_{it}}{I_{it}}\cdot dt \tag{3.5}$$

Therefore, the relative change in energy consumption per unit of added value can be divided into the contributions of the structure effect and the intensity effect.

$$\frac{I_T}{I_0} = \underbrace{\exp\left\{\int_0^T \sum_i \frac{E_{it}}{E_t}\cdot \frac{\dot{S}_{it}}{S_{it}}\cdot dt\right\}}_{\text{Structureeffect}D_{str}} \cdot \underbrace{\exp\left\{\int_0^T \sum_i \frac{E_{it}}{E_t}\cdot \frac{\dot{I}_{it}}{I_{it}}\cdot dt\right\}}_{\text{Intensityeffect}D_{int}} \tag{3.6}$$

Equation 3.6 is the exponential decomposition in consecutive form. In practical applications, data are always discrete. Therefore, we can convert it to a discrete form according to the integral mean value theorem. Both Törnqvist's (1936) exponential method and Sato's (1976) and Vartia's (1976) exponential method can be adopted. Here, we choose the latter method because it is more accurate.

$$I_T/I_0 = D_{str} \cdot D_{int} \cdot D_{res} \tag{3.7}$$

In this formula, D_{str} =, D_{int} =, D_{res} is part of the residual value and it is closer to 1 and represents the contributions of the structure effect and the intensity effect in sector i; the greater the value, the more the contribution. If the data are negative, the contribution is negative.

$$\alpha_i = \frac{\left(\frac{E_{iT}}{E_T} - \frac{E_{i0}}{E_0}\right) \Big/ \left(\ln\frac{E_{iT}}{E_T} - \ln\frac{E_{i0}}{E_0}\right)}{\sum_j \left[\left(\frac{E_{iT}}{E_T} - \frac{E_{i0}}{E_0}\right) \Big/ \left(\ln\frac{E_{jT}}{E_T} - \ln\frac{E_{j0}}{E_0}\right)\right]} \cdot (\ln S_{iT} - \ln S_{i0}) \tag{3.8}$$

$$\beta_i = \frac{\left(\frac{E_{iT}}{E_T} - \frac{E_{i0}}{E_0}\right) \Big/ \left(\ln\frac{E_{iT}}{E_T} - \ln\frac{E_{i0}}{E_0}\right)}{\sum_j \left[\left(\frac{E_{iT}}{E_T} - \frac{E_{i0}}{E_0}\right) \Big/ \left(\ln\frac{E_{jT}}{E_T} - \ln\frac{E_{j0}}{E_0}\right)\right]} \cdot (\ln I_{iT} - \ln I_{i0}) \tag{3.9}$$

(2) Divisia exponential decomposition method in absolute quantity form
For Eq. 3.2, we make the curve integral and get

$$\int_\Gamma \dot{I}_t = \int_\Gamma \sum_i \frac{E_{it}}{Y_t} \cdot \frac{\dot{S}_{it}}{S_{it}} + \int_\Gamma \sum_i \frac{E_{it}}{Y_t} \cdot \frac{\dot{I}_{it}}{I_{it}} \tag{3.10}$$

This is the integral path, representing the curve segment (S_t, I_t) in time interval (0, T). Thus,

$$I_T - I_0 = \underbrace{\int_0^T \sum_i \frac{E_{it}}{Y_t} \cdot d\ln S_{it}}_{\text{Structureeffect}\Delta I_{str}} + \underbrace{\int_0^T \sum_i \frac{E_{it}}{Y_t} \cdot d\ln I_{it}}_{\text{Intensityeffect}\Delta I_{inc}} \tag{3.11}$$

Similarly, according to the integral mean value theorem, we can convert it into a discrete form using Sato-Vartia's exponential method.

The absolute amount of change in energy consumption per added value in an industrial sector, ΔI, can be divided into two parts: the structure effect, $I_{str,}$ and bI_{int}

$$\Delta I = I_T - I_0 = \Delta I_{str} + \Delta I_{int} + \Delta I_{rsd} \tag{3.12}$$

In this formula, $\Delta I_{str} = \sum_i \omega_i$ and $\Delta I_{int} = \sum_i \varphi_i$, where ΔI_{rsd} represents the residual value and it is closer to 0.

Using Sato-Vartia's exponential method,

$$\omega_i = \frac{\left(\frac{E_{iT}}{Y_T} - \frac{E_{i0}}{Y_0}\right) \Big/ \left(\ln\frac{E_{iT}}{Y_T} - \ln\frac{E_{i0}}{Y_0}\right)}{\sum_j \left[\left(\frac{E_{iT}}{Y_T} - \frac{E_{i0}}{Y_0}\right) \Big/ \left(\ln\frac{E_{iT}}{Y_T} - \ln\frac{E_{i0}}{Y_0}\right)\right]} \cdot (\ln S_{iT} - \ln S_{i0}) \tag{3.13}$$

$$\varphi_i = \frac{\left(\frac{E_{iT}}{Y_T} - \frac{E_{i0}}{Y_0}\right) \Big/ \left(\ln\frac{E_{iT}}{Y_T} - \ln\frac{E_{i0}}{Y_0}\right)}{\sum_j \left[\left(\frac{E_{iT}}{Y_T} - \frac{E_{i0}}{Y_0}\right) \Big/ \left(\ln\frac{E_{iT}}{Y_T} - \ln\frac{E_{i0}}{Y_0}\right)\right]} \cdot (\ln I_{iT} - \ln I_{i0}) \tag{3.14}$$

The extent of a sector's subdivisions will affect the results. We can get different results when dividing the sectors according to category, major class, middle class, and small class. In general, more detail in terms of the subdivisions enables the energy consumption per added value in all subsectors to reflect the technological level better and the results more accurately; however, this approach will need more data.

3.1.2.2 The Data Sources and Processing

The data for added value in all sectors is from *China's Input–Output Table in 1997* (called "Table 1997") (NBS-DNA 1999) and *China's Input–Output Table in 2002* (called "Table 2002") (NBS-DNA 2006). Data for energy consumption is from China's Energy Statistics Yearbooks of 1997–1999 (NBS-DITS 2001) and China's Energy Statistics Yearbook of 2006 (NBS-DITS and NDRC-BE 2007).

The standards of input–output tables and statistics yearbooks are different: the former is divided by product and the latter is divided by industry. However, there is little difference in the level of the industrial major categories, so the difference can be ignored and we can treat them as comparable sources of information. The industry division of China's Energy Statistics Yearbooks of 1997–1999 adopts the National Economic Industry Classification and Code (GB/T4754-94) while China's Energy Statistics Yearbook of 2006 adopts the National Economic Industry Classification (GB/T4754-2002). But in the industrial area, their differences are very small. To keep consistent data standards, we set GB/T4754-94 to be the main criterion and combine some industries in the GB/T4754-2002 classification. According to the public information about the energy statistics in China, we set the industrial major categories as the criterion and divide the industry sectors into 36 subsectors.

As Fig. 3.7 shows, China's energy consumption by industrial subsectors is mainly in coal mining (A1), oil and gas production (A2), petroleum processing (A17), chemical engineering (A18), building materials (A23), iron and steel (A24), nonferrous metals (A25), and electricity (A34). Energy consumption in other industries takes up only a small percentage of the total industrial energy consumption.

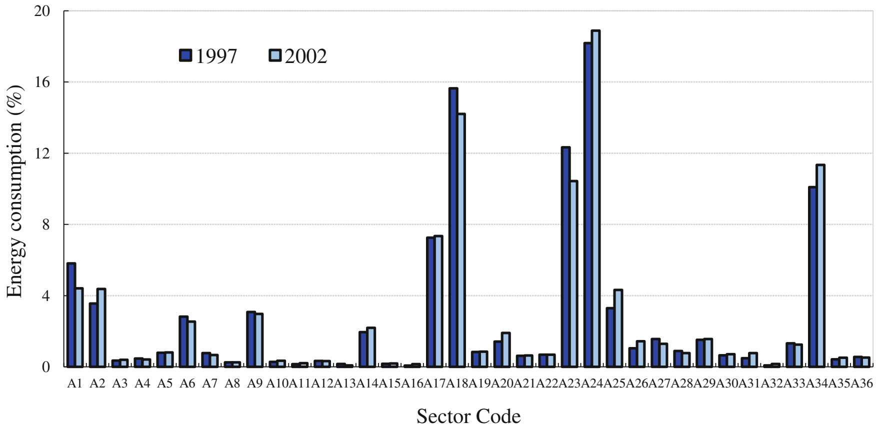

Fig. 3.7 The percentages of energy consumption in China by subsector (1997 and 2002) Data source: authors' calculations

Data in "Table 1997" and "Table 2002" are determined by producer prices in the current years; thus, the data of added value needs to be transformed into comparable prices. The National Bureau of Statistics has already amended "Table 2002" according to the results of FNEC but not yet amended "Table 1997." According to the "announcement about the amendment of China's historical GDP data," industrial added value in 1997 only increased by 1.6 % (calculated by the prices in that year) and the deviation was very small. Therefore, the data of the added value for the industrial sectors was adopted from "Table 1997" directly.

When disaggregating the energy consumption per unit of added value by sector for the 1997–2002 period, we set the price in 2002 as the base price. For the subsectors whose products are relatively simple, the change in added value is measured by the production in those particular subsectors while the added value for the other subsectors is deflated by the cost price index.[5] The added value percentages for all industries are shown in Fig. 3.8. During the 1997–2002 period, the ratio of the unit added value in some industries, such as the chemical industry (A18) and electricity (A34), is not very different while those in some industries, such as coal mining (A1), oil and gas production (A2), transportation equipment manufacturing (A29), communications, computer, and other electronic equipment manufacturing (A31), is significantly different.

[5]Strictly speaking, the cost price index is the price index of gross output, which is different from the price index of added value. However, considering the accounting method for added value in China, we employ the cost price index.

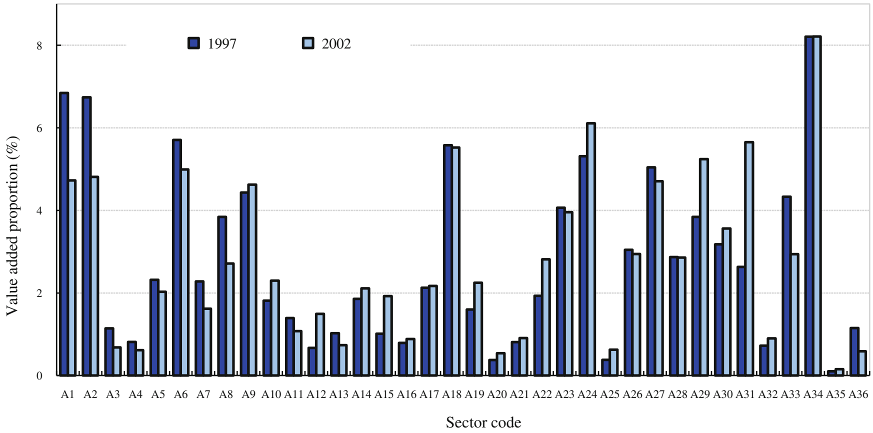

Fig. 3.8 The percentages of added value in China's subsectors (1997 and 2002). *Data source* authors' calculations

3.1.2.3 The Results of the Decomposition and Related Discussion

(1) The variations in the characteristics of energy consumption per unit of added value by subsector during the 1997–2002 period
To make it more convenient for calculating the contribution of the structure effect and the intensity effect to the change in energy consumption per unit of added value, we set the definitions as follows:
The contribution of the structure effect

$$C_{str} = \frac{\Delta I_{str}}{\Delta I_{str} + \Delta I_{int}} \times 100\,\% \tag{3.15}$$

The contribution of the intensity effect

$$C_{int} = \frac{\Delta I_{int}}{\Delta I_{str} + \Delta I_{int}} \times 100\,\% \tag{3.16}$$

Table 3.1 shows the results of our calculations. During the 1997–2002 period, energy consumption per unit of added value in China's industrial sector decreased from 3.01 tons of coal equivalent to 2.16 tons of coal equivalent for every 10,000 RMB. The contribution of the industrial structure adjustment (divided by the industrial major category) was −6.2 % while the contribution of the change in energy intensity was 106.2 %. This reflects the fact that during the 1997–2002 period, the dramatic decline in energy consumption per unit of added value in China's industrial subsectors contributed to the decline in energy consumption per unit of added value in the sector (including technological improvements and internal structural adjustments for all subsectors) while the contribution of the

Table 3.1 Decomposition results of the change in energy consumption per unit of added value in China by subsector (1997–2002)

Period	Relative quantity form				Absolute quantity form (tce/10^3 Yuan)					
	D_{tot}	D_{str}	D_{int}	D_{res}	ΔI_{tot}	ΔI_{str}	ΔI_{int}	ΔI_{rsd}	C_{str} (%)	C_{int} (%)
1997–2002	0.717	1.021	0.702	1.000	−0.851	0.053	0.903	0.000	−6.2	106.2

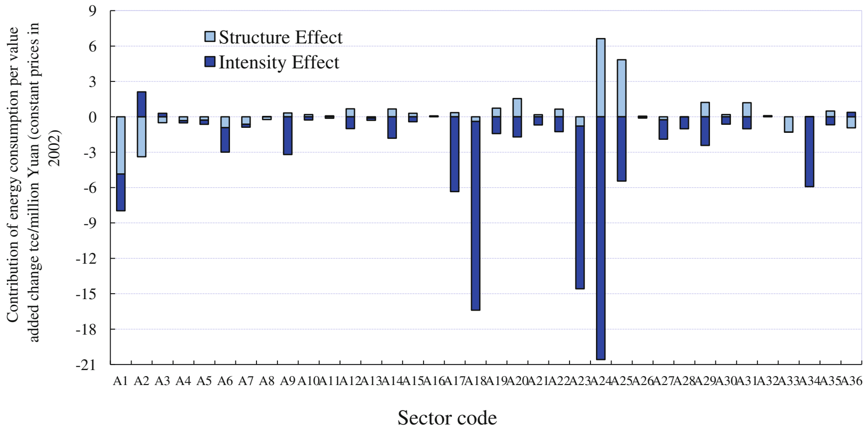

Fig. 3.9 Change in the industrial contribution of energy consumption per unit of added value in China (1997–2002). *Data source* authors' calculations

change in industrial structure was nil or even negative. This conclusion is consistent with the research by Lin (1996) for the 1981–1992 period, using the input–output tables of 1981 and 1987 and by Garbaccio et al. (1999), using the input–output tables of 1987 and 1992.

Figure 3.9 shows the structure contribution and intensity contribution of all industries. For the industries whose energy consumption is above average (energy consumption per unit of added value), the structure contribution is negative when the percentage of their added value increases; otherwise, the contribution is positive. From the figure, we can conclude that the structure contribution is negative for some high-energy consumption industries; in particular, iron and steel (A24) and nonferrous metals (A25) play an important role. Except for a few industries such as oil and gas production (A2), the energy consumption per unit of added value for most industries is decreasing and the contribution of the intensity effect is positive. 52.8 % of the total decline in energy consumption per unit of added value can be attributed to four industries: chemical industry (A18), building materials (A23), iron and steel (A24), and nonferrous metals (A25) while 23 % can be attributed to coal mining (A1), petroleum processing (A17), and electricity (A34).

Because of the downturn of in domestic demand and influence of the Southeast Asian financial crisis, China's economy entered depression in 1997. The growth rate of energy intensity trades almost kept pace with that of industry, so the contribution of the structure effect to the decline in energy consumption per unit of added value was slightly below zero. This can also be shown from the production growth of the main energy-consuming products. As shown in Fig. 3.10, industrial added value during the 1997–2002 period increased by 55.0 % and cement, crude steel, electrolytic aluminum, and refined copper increased by 41.7, 67.4, 112.3, and 38.4 %, respectively. During this period, the energy consumption per unit of production for the main energy-consuming products decreased rapidly; for example,

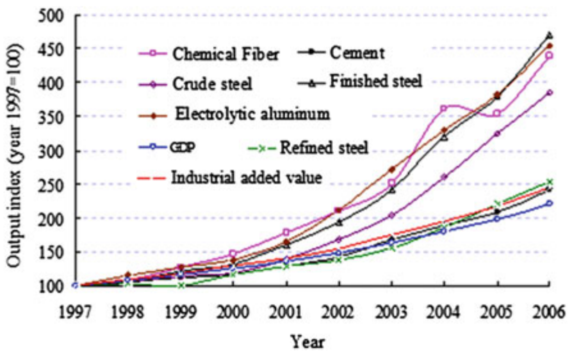

Fig. 3.10 Production indexes for China's main energy-consuming products (1997–2006). *Data sources* NBS (2007), CNMI (2000, 2003, 2005) and authors' calculations

the comparative energy consumption per ton of steel decreased by 23.8 % and the energy consumption per ton of cement decreased by 12.3 %, which played an important role in the contribution of the intensity effect.

(2) The variations in the characteristics of energy consumption per unit of added value by subsector during the 2002–2006 period
Since the second half of 2002, China's economy began a new round of fast growth. The industrialization process was obviously accelerating and the growth rate of real energy consumption was much faster than expected by most institutions and scholars. Compared with 2002, energy consumption per unit of GDP increased by 10.7 % in 2005 (coal equivalent calculation method). Although the growth rate reversed in the second half of 2006, energy consumption per unit of GDP only declined by 1.33 % for the whole year (even when using the Divisia method, it was only 2.3 %).
From According to the statistics, the main reason why energy demand increased dramatically in recent years is that some energy-intensity industries like iron and steel and building materials grew rapidly. As shown in Fig. 3.10, according to NBS (2007) and CNMI (2000, 2003, 2005) and our calculations, the production of crude steel was 182 million tons in 2002, and it increased by 1.44 times to 469 million tons in 2006. The production of electrolytic aluminum and cement increased by 1.14 times and 1.71 times, respectively, while GDP and the industrial added value increased by 48.6 and 58.4 %, respectively, over the same period. The growth rate for the production of high-energy consumer goods was much faster than that for the economy and industry as a whole.

Figure 3.11 shows the industry distribution by subsector in China in terms of energy consumption and the incremental changes during the 2002–2006 period. From the figure, we can conclude that the iron and steel sector (ferrous metal smelting and pressing) is the biggest consumer, making up 18.9 % of total energy consumption in the industrial sector in 2002 and increasing to 24.4 % in 2006. During the 2002–2006 period, approximately 83 % of the incremental energy consumption in the industrial sectors was from the following seven industries: coal, petroleum processing, chemicals, building materials, iron and steel, nonferrous metals, and

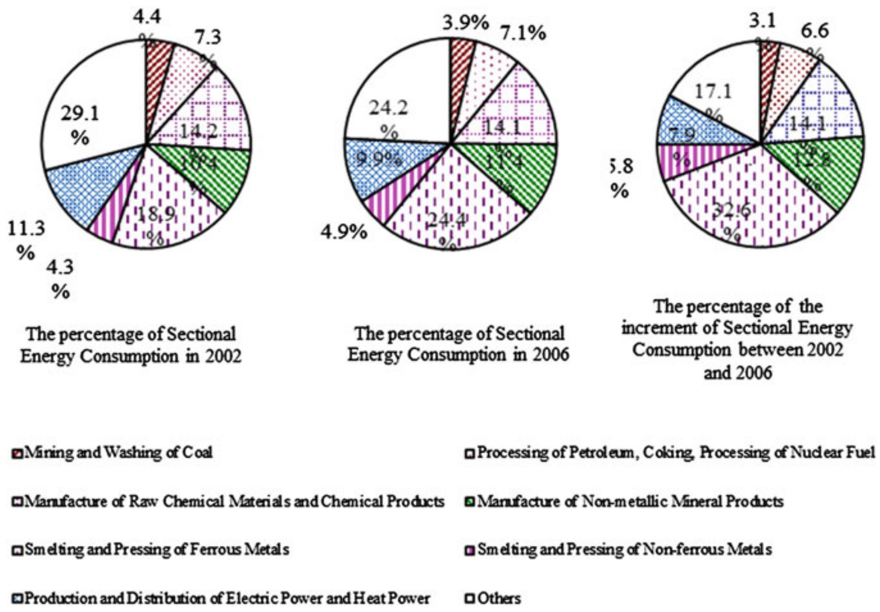

Fig. 3.11 Industry distribution of incremental energy consumption in China's industrial sector (2002–2006). *Data sources* NBS-DE and NBE-DCS (2008) and authors' calculations

electricity; among these, the iron and steel represented 32.6 %. These industries have high energy consumption per unit of added value, so they are the main industries in which to save energy both today and in the future. Except for its dependence on technological improvement, energy saving in the industrial sector should also emphasize the importance of optimizing and adjusting the industrial structure.

3.1.3 Further Discussion of the Decomposition Method

The contribution of the change in industrial structure to the decline of China's energy consumption per unit of GDP since 1978 is a controversial issue. Different quantitative research has produced different results, and the differences can be mainly attributed to these two aspects: (1) the hierarchy of the various industrial subdivisions is different (e.g., category, major class, middle class, small class) and (2) the conversion methods of the added value in constant prices are different, and some of the literature does not cope with this factor. If it is divided to the products hierarchy, then in the past 30 years, the contribution of the industrial structure to the energy consumption per unit of GDP is small on the whole. To avoid the problems about the price index, we can analyze the increase in the production of several products that consume the most energy. If we put the output index for 1978 as 1.0, then the GDP index for 2007 is 14.99, the finished steel index is 26.15, the cement index is 20.83, the plate glass index is 29.39, the ethylene index is 27.57, and the flint index is 12.84. The increase in the production of these products, which consume a lot of energy, is much higher than that for GDP in the same period.

This section uses the Divisia method to determine the factor decomposition of the change in energy consumption of the industrial sector per unit of added value during the 1997–2002 period from the perspective of value-added accounting. Research shows that at the industry level, the contribution of the change in industrial structure to the decline in the industrial energy consumption per unit of added value is −6.2 % during this period while that of the change in energy intensity for all industries is 106.2 %. The main reason why China's energy consumption increased sharply during the 2002–2006 period is because the industrial structure was changing toward an energy-intensive direction. During this period, 83 % of the added value in terms of the energy consumption of the industrial sector was from seven major industries: coal, petroleum processing, chemicals, building materials, iron and steel, non-ferrous metals, and electricity. Expediting the adjustment period and optimizing the industrial structure are important approaches to saving energy and improving efficiency not only in the past but also in the future.

Analyzing the reason for the change in energy macro-efficiency from the perspective of the industrial structure is not the only way to describe the statistical data to some extent. It answers the question, "What is it?" but not "Why is it?" It is certain that optimizing the industrial structure and enhancing the technology have policy implications for the energy improvement. However, it does not have much effect for supporting the macro decision because the change in industrial structure and technological improvement are endogenous to a great extent, and the internal reasons that lead to the changes in the industrial structure are still to be researched. Thus, further analysis will to be continued from the perspective of final demand in the next section of this chapter.

3.2 Final Demand Structure and Energy Efficiency

3.2.1 Marginal Energy Consumption of Different Final Demands

In this section, we will use the input–output method to study the relationship between final demand and energy consumption from the perspective of GDP (output) accounting. In total production, final demand includes consumption, capital formation, and net exports. Different final demands have different functions in promoting energy consumption. According to the data of China's input–output table, we analyze the promotion functions of final demand, such as capital formation, consumption expenditures of urban residents, consumption expenditures of rural residents, and government consumption expenditures, in terms of energy demand.

First, we define the marginal energy consumption as energy consumption per unit of final demand. For example, the marginal energy consumption for rural residential consumption is the increase in energy consumption (including direct and indirect consumption) per unit of rural residential consumption. The marginal energy consumptions of urban residential consumption, fixed capital formation, inventory changes, government consumption, exports, and imports are M_U, M_I, M_S, M_G, M_X, and M_M, respectively. Input–output analysis is an annual flow analysis that can also be used to forecast energy demand (Wei et al. 2006).

Suppose that $X = \begin{bmatrix} X_E \\ X_N \end{bmatrix}$ is the total output-value vector (the subscript E represents the primary energy sector and the subscript N represents the non-primary energy sector) and Z_E is the total output-physical vector of the primary energy sector. $\alpha_E = \begin{bmatrix} \alpha_1 \\ \alpha_2 \\ \vdots \\ \alpha_n \end{bmatrix}$ is the value coefficient vector of n kinds of energy, representing the output-value vector of energy i in a unit physical vector. α_E is the result of dividing Z_E into the corresponding elements of X_E, $Y = \begin{bmatrix} Y_E \\ Y_N \end{bmatrix}$ is the end-use (vector), $I = \begin{bmatrix} I_E & O \\ O & I_N \end{bmatrix}$ is a unit matrix and $A = \begin{bmatrix} A_E & A_{EN} \\ A_{NE} & A_N \end{bmatrix}$ is the direct consumption coefficient matrix. CON_R, CON_U, INV, STO, GOV, EX, IM are the rural residential consumption vector, urban residential consumption vector, fixed capital formation vector, inventory change vector, governmental consumption vector, export vector and import vector, respectively.

According to input-output analysis (UN 1999):

$$(I - A) \cdot X = Y \tag{3.17}$$

According to the GDP output accounting method:

$$Y = CON_R + CON_U + INV + STO + GOV + EX - IM + RES \tag{3.18}$$

In this formula, RES is the residual and we include it in the end use.
Therefore,

$$X = (I - A)^{-1} \cdot (CON_R + CON_U + INV + STO + GOV + EX - IM + RES) \tag{3.19}$$

In this formula, $(I - A)^{-1}$ is the Leontief inverse matrix.

And the marginal energy consumption coefficient of the residential sector is:

$$M_R = \frac{\left\|(\alpha_E)^T\right\|_E \cdot \left\|(I-A)^{-1} \cdot CON_R\right\|_E}{\|CON_R\|_S} \tag{3.20}$$

In Eq. 3.20, functional $\|Q\|_E$ means the vector formed by the first n elements of vector Q, $\|Q\|_S$ means the algebraic sum of all elements of vector Q. The method to calculate M_U, M_I, M_S, M_G, M_X, M_M is similar. According to the input-output method, energy output and energy input (including direct and indirect) are, respectively:

$$(\alpha_E)^T \cdot \left\|(I-A)^{-1} \cdot EX\right\|_E \quad \text{and} \quad (\alpha_E)^T \cdot \left\|(I-A)^{-1} \cdot IM\right\|_E$$

In China's input–output tables, which consisted of 42 sectors in 2005, the primary energy-supply sectors include "coal mining and washing," "oil and gas production," and "electricity, heating, producing, and supply," where the latter sector includes the production of secondary industry. From the above equation, we can make a preliminary calculation of the marginal energy consumption coefficients for all final demands: M_R, M_U, M_I, M_S, M_G and M_X. Using the ratio of hydropower and nuclear power to the total electricity production to calculate the total demand related to these primary power sources, the residual (*RES*) is allocated to the other final demand projections according to this ratio. In this way, we can derive all kinds of marginal energy consumption coefficients after making such an allocation.

To make easy comparisons, we calculate the influence of final demand to energy consumption in earlier years according to the input–output tables of 1981 (18 sectors), 1987 (64 sectors), 1990 (33 sectors), 1992 (118 sectors), 1995 (33 sectors), 1997 (124 sectors), and 2002 (122 sectors). The input–output table for 2000 only includes 17 sectors, so we do not adopt it here. China's input–output tables after 1997 totally adopt the System of National Accounts (SNA) while the earlier input–output tables incorporate the Material Product Accounting System (MPS) to different degrees. To standardize the data for consistency, we make some adjustments according to the relevant literature.

According to the data for the primary energy production, we can calculate the energy consumption driven by total final demand and its marginal energy consumption coefficient; then, according to the data for urban and rural residents, we can calculate the per capita energy consumption driven by urban and rural residential consumption in the same year. The results are shown in Tables 3.2 and 3.3.

From Table 3.3 and Fig. 3.12, we can see that the marginal energy coefficients for fixed capital formation are higher than those for urban and rural residential consumption in all years. In 2002 and 2005, the fixed capital formation per 10,000 RMB increased energy demand by 1.39 and 1.62 tons of coal equivalent, respectively; residential consumption per 10,000 RMB increased energy demand by 1.15 and 1.32 tons of coal equivalent, respectively; and the growth in the marginal energy coefficient for fixed capital formation was higher than that for residential

Table 3.2 Total energy consumption in China's final demand (1981–2005)

Year		Total energy consumption of household (million tons of coal equivalent)			Total energy consumption of fixed capital (million tons of coal equivalent)	Per capita total energy consumption of household (tons of coal equivalent)	
		Total	Rural	Urban		Rural	Urban
1981	Coal	264.27	142.25	122.02	160.09	0.178	0.605
	Crude oil	65.84	39.71	26.13	39.80	0.050	0.130
	Natural gas	10.82	6.80	4.02	5.47	0.009	0.020
	Hydroelectric	15.23	9.01	6.21	9.52	0.011	0.031
	Aggregated energy	356.15	197.77	158.38	214.88	0.248	0.785
1987	Coal	329.73	197.03	132.7	299.26	0.241	0.480
	Crude oil and natural gas	83.18	45.29	37.89	75.80	0.055	0.137
	Hydroelectric	19.32	10.21	9.11	19.03	0.013	0.033
	Aggregated energy	432.23	252.53	179.7	394.09	0.309	0.649
1990	Coal	316.79	194.36	122.43	218.36	0.231	0.405
	Crude oil and natural gas	72.04	36.38	35.66	64.93	0.043	0.118
	Hydroelectric	22.45	11.19	11.25	18.81	0.013	0.037
	Aggregated energy	411.28	241.94	169.34	302.10	0.288	0.561
1992	Coal	416.99	236.94	180.05	238.55	0.279	0.560
	Crude oil	108.38	52.35	56.03	75.95	0.062	0.174
	Natural gas	15.29	7.78	7.51	6.18	0.009	0.023
	Hydroelectric	25.45	12.1	13.35	19.76	0.014	0.042
	Aggregated energy	566.11	309.17	256.94	340.44	0.364	0.799
1995	Coal	464.17	229.37	234.79	362.09	0.267	0.668
	Crude oil and natural gas	109.19	52.18	57.01	97.70	0.061	0.162
	Hydroelectric	39.59	19.66	19.93	30.65	0.023	0.057
	Aggregated energy	612.94	301.21	311.73	490.44	0.350	0.886
1997	Coal	384.1	189.54	194.55	409.89	0.225	0.493
	Crude oil	105.22	50.21	55.01	124.76	0.060	0.139
	Natural gas	14.9	7.0	7.9	6.36	0.008	0.020
	Hydroelectric	37.75	17.38	20.37	34.51	0.021	0.052
	Aggregated energy	541.96	264.13	277.83	575.53	0.314	0.704

(continued)

Table 3.2 (continued)

2002	Coal	440.52	124.55	315.97	428.85	0.159	0.629
	Crude oil and natural gas	150.94	41.84	109.10	190.31	0.053	0.217
	Hydroelectric	56.01	14.46	41.55	51.91	0.018	0.083
	Aggregated energy	647.48	180.86	466.62	671.07	0.231	0.929
2005	Coal	717.59	167.67	549.92	944.36	0.225	0.978
	Crude oil	158.07	39.40	118.67	225.17	0.053	0.211
	Natural gas	60.75	13.73	47.02	79.32	0.018	0.084
	Hydroelectric	936.41	220.80	715.61	1248.85	0.296	1.273

(1) In this table, urban residential consumption and primary energy consumption (total energy consumption, including direct and indirect energy consumption), which are determined by fixed capital formation, and urban residential energy consumption, which is determined by consumption, are calculated according to the input–output table. (2) Although the data in the input–output tables before 1995 have been adjusted in accordance with the related literature (agricultural census, industrial census, tertiary census, economic census, statistical yearbooks, existing research results, and so on), they are still influenced by the Material Products Accounting System (MPAS); therefore, the calculations before 1995 and after 1997 cannot be compared to a certain extent

Table 3.3 Marginal energy consumption coefficients of urban and rural residential consumption, and fixed capital formation (1981–2005)

Year	1981	1987	1990	1992	1995	1997	2002	2005
Household consumption	3.54	2.27	2.19	2.27	1.86	1.47	1.15	1.32
# Rural	3.34	2.4	2.34	2.37	1.84	1.41	1.02	1.15
# Urban	3.82	2.11	2.02	2.16	1.88	1.54	1.21	1.38
Fixed capital formation	4.75	3.72	3.07	2.36	2.05	2.08	1.39	1.62

The marginal energy consumption coefficient is the energy consumption per unit of final demand (tons of coal equivalent/10,000 RMB). The marginal energy consumption coefficients for residential consumption and fixed capital formation have been converted to constant 2005 prices according to the urban and rural residential consumption deflator, and the fixed capital formation deflator

consumption in both years; thus, final demand developed in an energy-intensive direction. From the perspective of total production, the growth rate of investment is higher than that of consumption, and lower investment is a bad choice for decreasing the growth rate of energy consumption. Thus, this relationship explains the reason why energy consumption increased sharply during the 2002–2007 period.

In 2002, China's investment rate was 37.9 % while during the 2003–2007 period, it fluctuated greatly in the range 41.0 and −43.2 %. In 2002, the final consumption ratio was 59.6 % while it decreased to about 48 % in 2007. During the 2003–2007 period, the growth rate of real investment was between 10.9 and 16.6 %

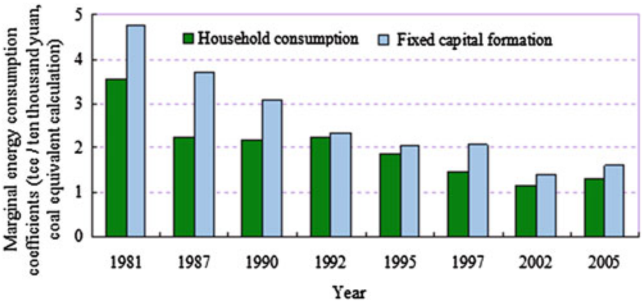

Fig. 3.12 Marginal energy consumption coefficients of China's residential consumption and investment (1981–2005). *Data source* authors' calculations

while the growth rate of real consumption was only between 6.6 and 10.0 %. The nominal growth rate of fixed capital investment for society as a whole was at a high level, ranging from 16.9 to 27.7 %, while the growth rate of total retail sales of consumer goods was 9.1–13.7 % (NBS 2009; World Bank 2010). The growth rate of China's energy consumption decreased in 2007. From the perspective of GDP output, the reason is that the growth rate of investment decreased while that of consumption increased; therefore, the contribution of consumption to economic growth was greater than that of investment for the first time.

From the perspective of urban and rural consumption, the marginal energy consumption coefficients of China's rural residential consumption in 1981, 1995, 1997, 2002, and 2005 were smaller than those of its urban residential consumption; that is, energy consumption determined by per unit rural residential consumption was smaller than that determined by per unit urban residential consumption. For all of the consumption expenditures of urban residents, the proportion of transportation, household goods, and living expenses are getting higher and higher, causing energy demand to rise rapidly. In recent years, the growth rate of urban residential consumption has been greater than that of rural residential consumption, which is also an important reason for the rapid growth in energy consumption. During the 2003–2006 period, the real consumption of China's urban residents increased annually by 9.7–11.8 % while that of its rural residents increased by −1.4–8.2 % (NBS 2007).

The marginal energy consumption coefficients of China's rural residential consumption were greater than those of urban residential consumption in 1987 and 1990. Aside from the GDP accounting method, the reasons are probably because (1) the process of rural economic restructuring has been faster since the 1980s and the income level of rural residents has risen significantly. The consumption structure has changed from a previous focus on buying food to purchasing clothing and paying for other household expenses, which have caused the marginal energy consumption coefficient to rise. (In fact, it did not rise because of the offsetting effect of technological improvement.) During this period, the growth rate of income per capita of rural residents was greater than that of urban residents, and the gap between

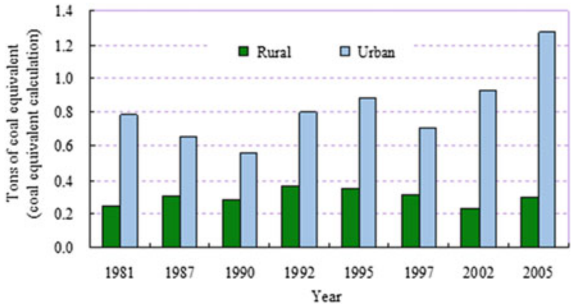

Fig. 3.13 Direct and indirect energy consumption per capita for China's urban and rural residents (1981–2005). *Data source* authors' calculations

rural and urban areas narrowed. The urban residential consumption structure has been upgraded since 1990, causing the marginal energy consumption coefficient to increase. During this period, the growth rate of income per capita of urban residents was greater than that of rural residents. (2) Since the various input–output tables are constructed differently, some direct and indirect energy consumption by urban residents, such as for living, heating, and electricity in the earlier years, are not included in residential consumption. Instead, they are included as state-owned enterprise expenditures or government expenditures. Thus, the marginal energy consumption coefficient for urban residential consumption is underestimated.

As shown in Fig. 3.13, the difference in energy consumption per capita (including indirect consumption) between urban and rural residents has been getting bigger since 1997, when energy consumption per capita for the rural residents was 44.6 % that of the urban residents and decreased to 23.3 % in 2005. It is not only bad when there is a decrease in the growth rate of energy demand, but it is also bad in the context of promoting energy fairness within a society.

3.2.2 Study on the Expenditure Elasticity of Residual Energy Consumption

The elasticity of the energy demand in different income groups to consumption expenditure is different by group. Because of data restrictions, we analyze the data of residential electricity consumption directly. Thirty provinces, cities, and autonomous regions were divided into two groups according to the consumption per person (one group of low consumption in area A and another group of high consumption in area B) in 2006, in which each group included 15 regions. Considering the distinct price levels among different areas, we use the research of Brandt and Holz (2006) and the consumer price index of the different areas during the 2005–2006 period, adding the residents' purchasing power parity index (PPP) of the different urban and rural areas in 2006 (Beijing = 1.00) to reduce the consumption expenditure per person for all regions. A one-element regression model is constructed, as presented below:

$$\ln E_{\mathrm{elec}} = \beta_0 + \beta_1 \cdot \ln X \tag{3.21}$$

In this model, E_{elec} is the residential electricity consumption per person and X is the consumption expenditure per person (using the regional PPP to reduce the expenditures). Usually, β_1 is greater than 0. For both the urban and rural residents, if the β_1 of group A is greater than that of group B and the data is significant in the statistics, then the elasticity of demand for residential electricity in terms of the consumption expenditure per person of the high consumer group is greater than that of the low consumer group (strictly speaking, it is the high consumption areas and because of the constraints of the available data, we use the region's sectional data). The regression results are shown in Table 3.4.

From the results of the regression model, there is not much difference when using ordinary least squares (OLS) or weighted least squares (WLS). According to WLS, the elasticities of electricity to the consumption expenditures for urban residents in group A and group B are 0.594 [0.620] and 1.334 [0.004], respectively. The result for the latter group is twice that of the former group and the statistics of the former are not outstanding. It shows that the elasticity of the electricity demand to the consumption expenditures in the high-consumption group (area) is larger than that in the low consumption group (area) in urban areas. For rural residents, the elasticities of group A and group B are 1.177 [0.027] and 1.513 [0.001], in which

Table 3.4 The elasticity of electricity consumption of China's urban and rural residents to residential consumption (2006)

	Coefficients	Low consumption areas (A)		High consumption areas (B)	
		OLS	WLS	OLS	WLS
Urban	β_0	−0.121	0.311	−6.770	−6.569
		(10.952)	(10.587)	(3.428)	(3.503)
		[0.991]	[0.977]	[0.070]	[0.083]
	β_1	0.642	0.594	1.356	1.334
		(1.211)	(1.171)	(0.370)	(0.379)
		[0.605]	[0.620]	[0.003]	[0.004]
	R^2	0.040	0.033	0.625	0.612
Rural	β_0	−5.799	−4.905	−7.462	−7.416
		(4.628)	(3.815)	(2.914)	(2.889)
		[0.232]	[0.221]	[0.024]	[0.023]
	β_1	1.288	1.177	1.520	1.513
		(0.575)	(0.473)	(0.340)	(0.336)
		[0.043]	[0.027]	[0.001]	[0.001]
	R^2	0.315	0.332	0.440	0.443

Independent variable is consumption expenditure per capita. OLS represents the ordinary least squares. WLS represents the weighted least squares. Weight represents the square root of the regional population. Data in parentheses is the standard deviation and the data in square brackets is the p-value of the two-sided test (both adjusted through White heteroscedasticity) the latter result is slightly more than the former result. It shows that the elasticity of electricity demand to the consumption expenditures in the high-consumption group (area) is greater than that in the low consumption group (area) in rural areas. Although the elasticity of the rural residents is slightly larger than that of urban residents, the energy consumption per person in the urban areas of China is 1.88 times that of the rural areas (in 2006). Even though the consumption growth of rural residents is higher than that of urban residents, it still helps in reducing the total energy consumption.

The input–output analysis and the regression analysis show that (1) the per unit energy demand that is driven by investment is larger than that driven by residential consumption; (2) the per unit energy demand driven by urban residential consumption is larger than that by rural residential consumption; and (3) the elasticity of energy demand to residential consumption in the high consumption group (area) is larger than that in the low consumption group (area).

Therefore, from the perspective of final demand, to keep China's economy growing rapidly and, at the same time, decrease its level of energy consumption and slow down its growth rate, it is better to adjust the ratio between investment and consumption and the ratio between urban residential consumption and rural residential consumption and to improve the contribution of residential consumption, especially the rural residential consumption in terms of economic growth. There will be some further discussions about the direct energy consumption per person for urban and rural residents in Sect. 3.4 of this chapter.

3.2.3 Analysis of the Elasticity of Energy Macro-efficiency to the Investment Ratio

It is expected that in the drive to improve technology, the change in the energy macro-efficiency is also affected by the change in the economic structure. From the perspective of final demand, the economic growth includes the growth of investment, consumption, and net exports. Even though China's investment structure has been changing since 1993, relatively speaking, in the current development phase, investment growth has sometimes contributed to an expansion of the high-energy consumption industry, an increase in the investment ratio and a rise in energy consumption per unit of GDP. Because of the inertia of economic growth, energy consumption per unit of GDP in the current period is also influenced by that of the previous period. Considering all of the above factors, we build an econometric model and quantitatively study the influence of the investment ratio to energy consumption per unit of GDP for the time period from 1993 to 2006.

$$\ln \boldsymbol{I}_{\mathrm{t}} = \beta_0 + \beta_1 \cdot \mathrm{r}_1 + \beta_2 \cdot \ln \boldsymbol{I}_{\mathrm{t}-1} \tag{3.22}$$

To represent energy consumption per unit of GDP, we use the Divisia method and the coal consumption method at time t, where r_t is the investment ratio at t and

Table 3.5 The relationship between China's investment ratio and energy consumption per unit of GDP

Independent variable	Dependent variable	
	$\ln I_t^{div}$	$\ln I_t^{ce}$
Intercept	−0.402	−0.457
	(−0.118)	(−0.062)
	[0.007]	[0.000]
r_t	0.006	0.012
	(−0.003)	(−0.002)
	[0.037]	[0.000]
$\ln I_{t-1}^{div}$	0.854	
	(−0.041)	
	[0.000]	
$\ln I_{t-1}^{ce}$		0.865
		(−0.021)
		[0.000]
AR(2)		−0.931
		(−0.302)
		[0.018]
R^2	0.956	0.984
$\bar{R}^2$	0.948	0.977
D.W. statistic	1.941	–
F statistic	109.4	140.9

Figures in round brackets are the standard deviation and figures in square brackets are the p-value of a two-sided test, which is adjusted using the Newey-West method. When employing the coal equivalent calculations in our regressions, there is a two-order sequence relevance through the Q statistics test, so it adopts a two-order lag residual error

is represented by the rate of capital formation. It can be expected that $\beta_1 > 0$ and that a rise in the investment ratio will increase the energy consumption per unit of GDP. When $0 < \beta_2 < 1$, it indicates an improvement in technology. The results of the econometric analysis are shown in Fig. 3.5 (Table 3.5).

According to the regression results, the coefficients of ln and ln β_2 are closer, and both are less than 1, indicating that with the change in time, energy consumption per unit of GDP has a natural tendency to decline, whether not one uses the coal consumption method or the Divisia method, and this result mainly contributes towards technology improvement.

According to the coal consumption method, when the investment ratio rises by 1 percentage point, the energy consumption per unit of GDP will increase by about 1.2 %; but according to the Divisia method, it will increase by about 0.6 % ((Exp (0.012) − 1) ∗ 100 %; (Exp(0.006) − 1) ∗ 100 % = 0.6 %). In recent years, China's total energy consumption has grown rapidly and the main reason is that the growth of investment has been very fast and the resulting investment ratio has been too high. The results using the coal consumption method and the Divisia method are different in that the former is larger than the latter. The reason is that China's primary energy consumption is mainly coal, so during a period when the growth of investment is relatively fast and the investment ratio is rising, the growth rate of coal demand is faster than that of oil demand and the coal consumption ratio increases. Thus, the growth rate of total energy consumption as calculated by coal consumption method is higher than that calculated by the Divisia method.

China's investment continues to be mainly in sectors related to civil engineering and in infrastructure tending towards high energy consumption. This is why energy consumption has risen rapidly in recent years. Since 2000, construction and installation projects have always taken up more than 60 % of the investment in social fixed capital while the purchase of tools and instruments has been only 20–25 % (NBS 2007). According to the input–output tables consisting of 122 sectors in 2002, we can calculate the industrial demand structure of investment. The construction industry is mainly part of the investment expenditures and its expenditures are calculated to represent 62.5 % of gross fixed capital formation. These large-scale civil engineering projects sometimes consume large quantities of energy-intensive products, shaping the feature of heavy chemical industry, which is dominated by the raw material industry. As the investment ratio is too high, it is difficult to maintain a rapid decline in the energy consumption per unit of GDP and this factor is also related to the system of national income distribution, which is discussed in Sect. 3.3.

3.2.4 *Analysis of the Direct and Embodied Energy Exports*

One of the outstanding features in the growth of China's foreign trade in recent years is that the ratio of resource product exports is relatively large, leading to a lot of indirect energy exports. As shown in Table 3.6 (according to the results of the input–output method in Sect. 3.2.1), during the 1997–2005 period (especially in the

Table 3.6 The amount and ratio of China's direct and indirect energy exports (1997–2005)

<table>
<tr><th>Year</th><th>Coal</th><th>Crude oil</th><th>Natural gas</th><th>Electricity</th><th>Aggregation</th><th>Energy export proportion of national energy consumption (%)</th><th>Goods and service export proportion of GDP (%)</th></tr>
<tr><td>1997</td><td>24,739</td><td>10,342</td><td>1185</td><td>2081</td><td>38,348</td><td>27.8</td><td>21.9</td></tr>
<tr><td>2002</td><td>31,977</td><td colspan="2">15,408</td><td>3605</td><td>50,990</td><td>33.6</td><td>25.4</td></tr>
<tr><td>2005</td><td>88,525</td><td colspan="2">22,875</td><td>7132</td><td>118,531</td><td>52.8</td><td>37.1</td></tr>
</table>

We used the input-output model to calculate the energy consumption, except for fixed capital depreciation. In the input-output tables of 2002 and 2005, the oil and gas industries were combined into one sector; thus, in these years, their consumption is amalgamated. Unit: 10,000 tons of coal equivalent last three years), China's energy exports (including indirect exports and using the coal consumption method)[6] increased from 380 to 1190 million tce, with the percentage of the total national energy consumption rising from 27.8 to 52.8 %. Comparing the percentages that product and service exports represent in terms of GDP, China's export trade shows a significantly high energy-intensity, and the extent of the intensity is still rising. Most energy exports are related to the indirect exports formed by the energy-carrying products. In 2005, direct energy exports were only 1140 million tce, or 10 % of total exports. China transformed from a net exporter of steel to a net importer of steel in 2005 and by 2007, steel exports were 45.8 million tons (NBS 2008b) and indirect energy exports were about 40 million tons.

Quite a few of the industries that export a lot of high energy consumer products do not have a comparative advantage in China and the additional value of the products is low. For example, steel exports are mainly low-end products. The reason for this phenomenon is that the price of resources, such as land, water, and energy, is relatively low (refer to the research in Sect. 2.2.4), and the production capacity surplus of some industries built by the large amounts of previous investment. It is difficult to reverse the current export trend in a short time. If a country carries out strict political or economic measures to reduce exports and its growth rate, exporters will suffer significant losses, which could even lead to a negative impact on the operation of the whole macro economy and on social stability. The common problems formed by history can only be solved gradually by adjusting future growth. To optimize the foreign trade export structure, and apart from the financial and tax policies made directly by the foreign trade department, some efforts still need to be made in regulating the price of resources, enhancing the protection of the environment, encouraging the innovations in production and technology, and so on.

3.3 Impact of the National Income Distribution Structure on Energy Demand

3.3.1 Analysis of the Income Elasticity of Household Energy Demand

Similar to Table 3.4 in Sect. 3.2, we adopt the regression of the logarithm of per-capita electricity consumption to the logarithm of X (per capita income). Then, we get β_1, which is the elasticity of E_{elec} on X. The grouping method is similar to

[6]Because input–output analysis belongs to the flow-analysis methods, energy exports here does not include the energy consumption caused by fixed capital. If this consumption is added, then the energy exports would be larger.

Table 3.7 Income elasticity of the electricity consumption of China's urban and rural households

	Coefficient	Low-consumption group (A)		High-consumption group (B)	
		OLS	WLS	OLS	WLS
Urban areas	β_0	20.408	19.545	−2.443	−2.291
		(11.142)	(11.189)	(2.121)	(2.149)
		[0.090]	[0.104]	[0.270]	[0.306]
	β_1	−1.613	−1.518	0.880	0.863
		(1.218)	(1.224)	(0.224)	(0.227)
		[0.208]	[0.237]	[0.002]	[0.002]
	R^2	0.099	0.092	0.563	0.548
Rural areas	β_0	−6.245	−5.737	−6.121	−6.365
		(2.857)	(2.692)	(1.648)	(1.527)
		[0.048]	[0.053]	[0.003]	[0.001]
	β_1	1.370	1.307	1.385	1.414
		(0.357)	(0.337)	(0.197	(0.182)
		[0.002]	[0.002]	[0.000]	[0.000]
	R^2	0.618	0.613	0.833	0.835

Numbers in parentheses are the standard deviation and numbers in square brackets are the two-sided test p-values (after a White different variance adjustment). OLS represents the ordinary least squares method. WLS stands for the weighted least squares method, where the weight is the square root of the logarithm of the regional population

that of Table 3.4. According to income, there are 15 different regions. The regression results are shown in Table 3.7.

$$\ln E_{elec} = \beta_0 + \beta_1 \cdot \ln X \tag{3.23}$$

From the regression results, the differences are small whether or not the ordinary least squares (OLS) method or the weighted least squares (WLS) method is adopted. According to WLS, the coefficient of the urban areas in Group A is $\beta_1 \approx -1.518 < 0$, but it is not statistically significant; whereas the coefficient of the urban areas in Group B and the rural areas in both Groups A and B, β_1, is statistically significant. The differences in the elasticity between the rural areas in Groups A and B are small, with Group B being slightly higher. The possible explanation is that the overall income level of rural households was still relatively low and the differences of the consumption structure were not significant. Per capita electricity consumption of urban households was 1.88 times that of rural households (2006). Consequently, from the viewpoint of the household income distribution structure, the increasing income growth rate of the rural and urban low-income groups contributed to energy conservation. This has an important meaning in achieving sustainable economic growth, advancing social harmony, promoting energy equity, and reducing energy poverty.

(1) In the long run, after the income of rural households increases, their energy consumption behavior tends to converge to that of urban households. In addition, they will need more energy-intensive products and services. However, in the present stage, the adjustments in the income distribution structure and the efforts to improve household income are actually slowing down the increase in the overall marginal energy consumption coefficient. Considering that there will be more efficient and cleaner energy-saving technologies in the future, energy efficiency will also improve after a substantial growth in the income level of rural households. (2) Improving energy efficiency and optimizing the structure of income distribution are not contradictory, nor is there the a relationship between the means and the end. The purpose of optimizing the structure of income distribution mainly lies in promoting social equity and harmony. In this sense, improving the energy efficiency is a byproduct of optimizing the income distribution structure.

3.3.2 Changes in the Income Distribution Pattern and Its Impact on Energy Consumption

As shown in Table 3.8, according to NBS (2010), World Bank (2010), and our own computations, investment in China in recent years has grown faster than consumption, leading to a rise in the investment rate, a decline in the consumption rate, and a rapid growth in energy demand. This is, to some extent, investment is determined by the stage characteristics of China's economic and social development. But it is not enough to fully explain the inharmonious relationship between investment and consumption and the distortions of the investment structure. From the income approach, the reason for an extraordinary rise in the investment rate is the unreasonable distribution structure of national income: the economy is growing rapidly and company profits are increasing sharply while the growth of household income (mainly rural residents and other low-income groups) is relatively slow.

In recent years, the per capita net income of rural households has been three to five percentage points lower than the average growth rate of per capita GDP (the situation has improved since 2007). In the large-scale industrial enterprises, corporate profits accounted for 17.5 % of the value added in 2002, which increased to 21.4 % in 2006. This proportion grew faster in the state-owned and state-holding industrial enterprises—from 16.5 to 26.0 %. The profits of some of the major energy-consuming industries grew even faster. In 2007, the state-owned enterprises realized a profit of 1.62 trillion yuan, representing a year-on-year growth rate of 31.6 %, in which the iron and steel industry increased by 116 %, the petrochemical industry by 95 %, the chemical industry by 63.7 %, and the power industry by 59.4 %.[7] China's total return on capital was approximately 23 % and it has shown an upward trend in recent years (Liao 2008). The rate of return on investment was

[7]Data source: The official website of the Ministry of Finance.

Table 3.8 Key indicators of the development of China's economy (2002–2009) (%)

Year	2002	2003	2004	2005	2006	2007	2008	2009
Proportion of total profits of all state-owned and above-scale industrial enterprises accounted for value added	17.5	19.9	21.8	20.5	21.4	–	–	–
Proportion of total profits of all state-owned and state holding industrial enterprises accounted for value added	16.5	20.4	23.5	24.0	26.0	–	–	–
Urban per capita disposable income growth	13.4	9.0	7.7	9.6	10.4	12.2	8.4	9.8
Rural per capita net income growth	4.8	4.3	6.8	6.2	7.4	9.5	8.0	8.5
Actual growth rate of fixed capital formation	13.2	16.6	11.9	11.0	10.7	10.9	8.8	17.3
Actual growth rate of household consumption	6.1	6.0	6.8	6.6	8.4	10.0	8.2	9.5
Actual growth rate of rural household consumption	4.0	−0.7	4.3	8.0	8.3	8.8	8.2	–
Actual growth rate of urban household consumption	9.0	10.1	9.4	10.1	12.7	12.0	10.0	–
Energy consumption growth (coal equivalent calculation)	6.0	15.3	16.1	11.1	10.2	8.3	8.0	6.5
Actual growth rate of GDP	9.1	10.0	10.1	11.3	12.7	14.2	9.6	9.1

Because of adjustments in the demographic and data dissemination systems, the value added for large-scale industry cannot be obtained after 2007

high, corporate profits rose rapidly, and most of the profits were retained (in particular, the state-owned enterprises). Residents expected that expenditures for future education, healthcare, housing, and other items would increase, so they had a higher propensity to save, and as a result, residential consumption growth was low. The high growth of household savings and corporate profits provided sufficient funds for the high growth of investments. This caused a rapid growth in energy requirements during the 2003–2006 period, and it was difficult to reduce energy consumption per unit of GDP. The logical relationship mentioned above is shown in Fig. 3.14.

Since 2007, the situation has improved, with rapid growth of household income and a narrowing of the gap in income growth rates between rural and urban households. This made a big contribution to the decline of annual energy consumption per unit of GDP during the 2007–2009 period. However, the national income distribution should be further adjusted and optimized; household income and consumption should be increased, especially for rural households and other low-income groups; and the industrial structure should be adjusted and optimized in terms of the demand side to reduce energy consumption and improve energy efficiency.

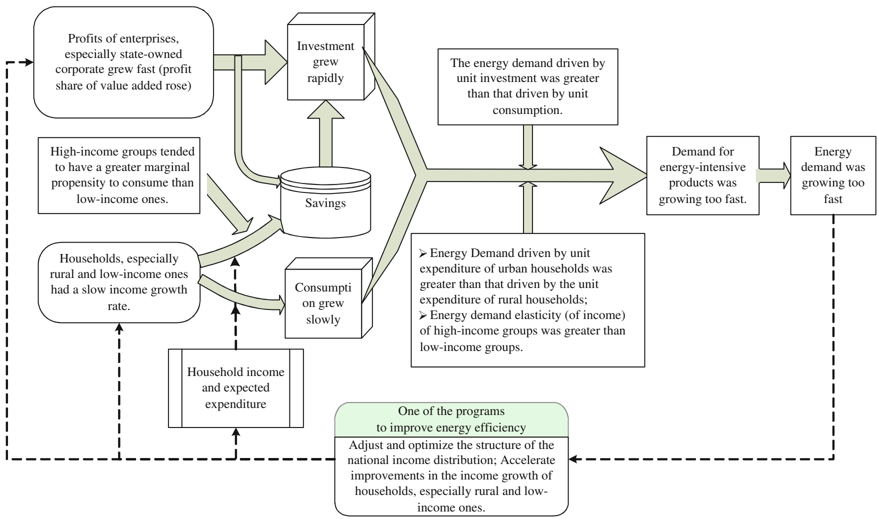

Fig. 3.14 Mechanisms of the influence of economic structure on energy efficiency

3.4 Research Methodology of the Influence of Urbanization on Energy Demand with Supporting Evidence

China's urbanization lags behind industrialization, which still needs to be expedited in the future. Accelerating the urbanization process will result in a rapid growth of energy demand. Urbanization leads to an increase in the direct and indirect energy use of households, whereas there is a need to build a large urban infrastructure during the urbanization process, which will consume a large amount of energy-intensive products. According to the study by the National Population Development Strategy Research Group (2007), China's urbanization rate should exceed 53 % by 2020 and urbanization should achieve the level of the moderately developed countries by 2050.

3.4.1 Research into Urbanization and Household Direct Energy Consumption Based on the Divisia Decomposition Method

In China, per capita energy consumption of urban households is 2–3 times that of rural households (excluding non-commercial energy). Since 1996, China's urbanization process has expedited significantly, with the urbanization growth rate rising from 0.5 percentage points per year to 1.2–1.4 percentage points per year (it declined slightly in 2006 and 2007, when it was 0.91 and 1.04 percentage points, respectively). In 2007, the urbanization rate reached 44.9 %. To quantitatively calculate the effect of urbanization on household energy consumption in China, we use the Sato-Vartia index method (the discrete form of the Divisia method). E_t stands for the total amount of household energy consumption in year t and $E_{1,t}$ and $E_{2,t}$ represent, respectively, the total amount of urban and rural household energy consumption in year t. N_t is for the population of year t. and $s_{1,t}$ and $s_{2,t}$ are the proportion of urban and rural population, respectively, which reflect the process the urbanization; and $e_{1,t}$ and $e_{2,t}$ represent per capita energy consumption of urban and rural households.

$$\dot{E}_t = \sum_{i=1}^{2} N_t \cdot s_{i,t} \cdot e_{i,t} \tag{3.24}$$

By differentiating Eq. 3.24 and reorganizing, we get:

$$\dot{E}_t = \underbrace{\sum_{i=1}^{2} E_{i,t} \cdot \frac{\dot{N}_t}{N_t}}_{\text{Effectofpopulationgrowth}} + \underbrace{\sum_{i=1}^{2} E_{i,t} \cdot \frac{\dot{s}_{i,t}}{s_{i,t}}}_{\text{Effectofurbanization}} + \underbrace{E_{1,t} \cdot \frac{\dot{e}_{1,t}}{e_{1,t}}}_{\text{Effectofper-capitaenergyuseinurban}} + \underbrace{E_{2,t} \cdot \frac{\dot{e}_{2,t}}{e_{2,t}}}_{\text{Effectofper-capitaenergyuseinrural}} \tag{3.25}$$

We apply the curvilinear integral to Eq. 3.25, followed by the Sato-Vartia index method to make the various parts of the effects into the discrete form. Using the 2007 China Statistical Yearbook (NBS 2007) and the 2007 China's Energy Statistical Yearbook (NBS-DE and NBE-DCS 2008), the factors influencing the direct energy consumption of Chinese households were calculated. The results are shown in Fig. 3.15.

Based on Eq. 3.25, the urbanization's contribution to the incremental household energy consumption during the 1991–1995 period was about 900–1300 thousand tons of coal equivalent per year and it increased to 2100–2800 thousand tons of coal

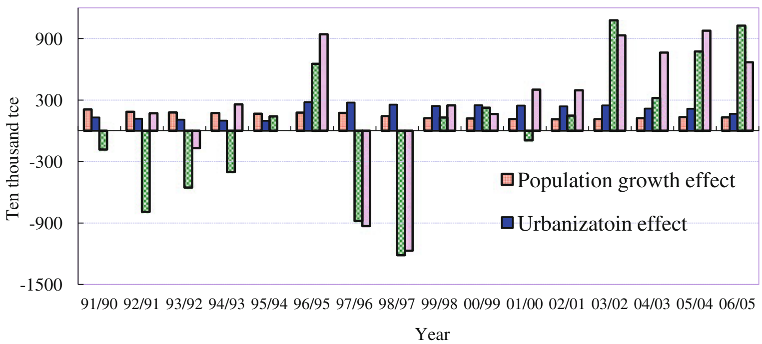

Fig. 3.15 Factor decomposition of the change in direct energy consumption for Chinese households (1990–2006). *Data source* authors' calculations

equivalent per year during the 1996–2006 period. Compared with 2002, China's direct energy consumption by households increased by 78.77 million tons of coal equivalent in 2006, in which population growth, a higher urbanization rate, and the growth in energy consumption by rural and urban households contributed 6.3, 10.8, 40.6, and 42.4 %, respectively. The urbanization rate increased 1 percentage point each year, giving rise to an increase of 1760 thousand tons of coal equivalent in the direct energy consumption of Chinese households (excluding the growth in energy consumption resulting from the changes in household income).

3.4.2 Research into Urbanization and Household Indirect Energy Consumption Based on the Input–Output Analysis Method

The process of urbanization has also brought about more household indirect energy consumption. Energy demand driven by the unit expenditures of urban households is greater than that driven by the unit expenditures of rural households. The per capita spending of urban residents is more than that of rural residents. The result of these two factors is that the per capita indirect energy consumption of urban households is much larger than that of rural households.

As shown in Table 3.9, which is based on the input–output analysis model, urban households in China consumed 716 million tons of coal equivalent in 2005 (including both direct and indirect energy consumption, where the indirect energy consumption does not include the previous energy consumption pertaining to capital losses [depreciation of fixed capital], whereas rural households consumed 221 million tons of coal equivalent). For per capita direct energy consumption,

Table 3.9 Direct and indirect energy consumption of China's urban and rural households (2002 and 2005)

Energy consumption	2002		2005	
	Urban	Rural	Urban	Rural
Total household energy consumption (million tons of coal equivalent)	466	181	716	221
#Direct energy consumption (million tons of coal equivalent)	106	69	144	91
#Indirect energy consumption (million tons of coal equivalent)	360	112	571	130
Total per capita household energy consumption (thousand tons of coal equivalent)	929	231	1273	296
#Direct energy consumption (thousand tons of coal equivalent)	216	87	257	122
#Indirect energy consumption (thousand tons of coal equivalent)	718	143	1016	174

urban households consumed 1.6 times more than rural households and for per capita indirect energy consumption, urban households consumed 3.4 times more. The urbanization rate increased by 1 percentage point per year, giving rise to an increase of 11 million tons of coal equivalent in the indirect energy consumption of households (excluding the energy consumption growth resulting from the changes in household income, urban and rural infrastructure, and residential construction).

3.4.3 Research into the Construction Industry and Energy Demand Based on the Input–Output Analysis Method

The process of urbanization requires the construction of a large urban infrastructure, including many houses, and it also consumes a large amount of steel, building materials, nonferrous metals, and other high energy-consuming products. Pursuant to the input–output analysis model, the 2002 direct and indirect energy consumption resulting from the total output of China's construction industry was 436 million tons of coal equivalent, accounting for 28.7 % of the country's total energy consumption. In 2005, the total grew to 664 million tons of coal equivalent, or 29.7 % of the country's total energy consumption, most of which was for urban construction.

Generally speaking, the spatial layout of China's cities has many obstacles both between and within the cities, resulting in a lot of wasted energy in terms of constructing the urban infrastructure and traffic systems. In many places, the functional layout of the cities is not systematic. In response to the massive energy demand due to urbanization, we should attach great importance to the process of urbanization and solve the problems of China's existing urban landscape, including the optimization of its urban functions, scientifically planning its urban spatial structure, improving and strictly enforcing the building energy-efficiency standards, preventing poor and redundant construction that leads to short-lived and temporary buildings, establishing an urban transportation system that is favorable to energy conservation, and prioritizing the development of public transport.

3.5 Conclusion

From the perspective of the production, expenditure, and income approaches of GDP accounting, this chapter integrates the input–output analysis method, the Divisia decomposition method, the regression analysis method, as well as other statistical indicators, to analyze in a step-by-step fashion the impacts of the industrial, final demand and national income distribution structures on energy demand and macro-energy efficiency. It also analyzes the relationship between economic growth, industrial growth, and urbanization and the growth in energy consumption, as well as the (declining) energy consumption per unit of GDP.

During the 1997–2002 period, the decrease in energy consumption per unit of value added in China's industrial sector was due to the decline in energy consumption per unit of value added for each industrial branch (divided by the major categories of industry) while the contribution of industrial restructuring was negative. The sharp increase in energy demand between 2002 and 2006, as well as the rise in energy consumption per unit of GDP, was mainly caused by the development of the industrial structure towards becoming more energy-intensive. Excessive investment growth, slow consumption growth, and relatively high export growth of energy-intensive products were important reasons why the industrial structure developed in an energy-intensive direction in recent years. Input–output analysis showed that the marginal energy consumption coefficient of investment was greater than that of consumption and that the marginal energy consumption coefficient of urban households was greater than that of rural households. A regression analysis showed that the income elasticity coefficient of electricity demand in high-income areas was greater than that in low-income areas.

The real reason why the uncoordinated proportional relationship between investment and consumption could lead to the rapidly growing energy consumption was that the national income distribution structure was incompatible. In recent years, corporate profits have grown quickly; however, income growth has been relatively slow for households, especially rural households and other low-income groups. In addition, residents expected an increase in future expenditures, so the marginal saving rate tended to be high and household consumption grew slowly. The high growth rate of household savings and corporate profits provided sufficient funds for a high grow rate of investment, resulting in a rapid growth in energy demand and difficulties in decreasing the energy consumption per unit of GDP. The slow growth rate in China's energy consumption in 2007 was due, in part, to a rapid growth in household income, a narrowing of the gap between consumption and investment growth, as well as the slowing growth rate of the energy-intensive industry.

Accelerating the improvement in household incomes, especially the income of rural households and other low-income groups, is advantageous when facilitating energy conservation and improving energy efficiency. This approach is in accordance with narrowing the income gap, promoting social harmony, reducing energy poverty, and advancing energy equity.

References

Ang BW (1997) Decomposition of aggregate energy intensity of industry with application to China, Korea and Taiwan. Energy Environ 8(1):1–11

Ang BW (2004) Decomposition analysis for policymaking in energy: which is the preferred method? Energy Policy 32(9):1131–1139

Ang BW (2005) The LMDI approach to decomposition analysis: a practical guide. Energy Policy 33(7):867–871
Ang BW (2006) Monitoring changes in economy-wide energy efficiency: from energy-GDP ratio to composite efficiency index. Energy Policy 34(5):574–582
Ang BW, Zhang FQ (2000) A survey of index decomposition analysis in energy and environmental studies. Energy 25(12):1149–1176
Brandt L, Holz CA (2006) Spatial price differences in China: Estimates and implications. Econ Dev Cult Change 55(1):43–86
China Nonferrous Metals Industry Association (2000) China Nonferrous Metals Industry yearbook. China Nonferrous Metals Industry Association, Beijing
China Nonferrous Metals Industry Association (2003) China Nonferrous Metals Industry yearbook. China Nonferrous Metals Industry Association, Beijing
China Nonferrous Metals Industry Association (2005) China Nonferrous Metals Industry yearbook. China Nonferrous Metals Industry Association, Beijing
Department of Comprehensive Statistics of National Bureau of Statistics (2010) China statistical data compilation 1949–2008. China Statistics Press, Beijing
Department of Energy of National Bureau of Statistics, Department of Comprehensive Statistics of National Energy Administration (2008) China energy statistical yearbook 2007. China Statistics Press, Beijing
Department of Energy of National Bureau of Statistics, Department of Comprehensive Statistics of National Energy Administration (2009) China energy statistical yearbook 2008. China Statistics Press, Beijing
Department of Energy of National Bureau of Statistics, Department of Comprehensive Statistics of National Energy Administration (2010) China energy statistical yearbook 2009. China Statistics Press, Beijing
Department of Industrial and Transport Statistics of National Bureau of Statistics (2000) Historical data on China's industrial traffic energy 1949–1999. China Statistics Press, Beijing
Department of Industry and Transport Statistics of National Bureau of Statistics (2001) China energy statistical yearbook 1997–1999. China Statistics Press, Beijing
Department of Industry and Transport Statistics of National Bureau of Statistics, Bureau of Energy of National Development and Reform Commission (2006) China energy statistical yearbook 2005. China Statistics Press, Beijing
Department of Industry and Transport Statistics of National Bureau of Statistics, Bureau of Energy of National Development and Reform Commission (2007) China energy statistical yearbook 2006. China Statistics Press, Beijing
Department of Industry and Transport Statistics of National Bureau of Statistics (2007) China energy statistical yearbook 2007. China Statistics Press, Beijing
Department of National Accounts of National Bureau of Statistics (2006) China input-output table 2002. China Statistics Press, Beijing
Garbaccio RF, Ho MS, Jorgenson DW (1999) Why has the energy-output ratio fallen in China? Energy J 20(3):63–91
Hulten CR (1973) Divisia index numbers. Econometrica 41(6):1017–1025
Liao H (2008) Study on econometric model of energy efficiency and its application. Dissertation, Chinese Academy of Sciences
Liao H, Fan Y, Wei Y-M (2007) What induced China's energy intensity to fluctuate: 1997–2006? Energy Policy 35(9):4640–4649
Lin X (1996) China's energy strategy: economic structure, technological choices, and energy consumption. Praeger Publishers, Connecticut London
National Bureau of Statistics (2007) China statistical yearbook 2007. China Statistics Press, Beijing
National Bureau of Statistics (2008a) National economic and social development statistical bulletin in 2007 of China. China Statistics Press, Beijing
National Bureau of Statistics (2008b) China statistical yearbook 2008. China Statistics Press, Beijing

National Bureau of Statistics (2009) China statistical yearbook 2009. China Statistics Press, Beijing

National Bureau of Statistics (2010) China statistical abstract 2010. China Statistics Press, Beijing

Sato K (1976) The ideal log-change index number. Rev Econ Stat 58(2):223–228

Törnqvist L (1936) The bank of Finland's consumption price index. Bank Finl Mon Bull 10:1–8

UN (1999) Handbook of input-output table compilation and analysis, New York

Vartia YO (1976) Ideal log-change index numbers. Scand J Stat Theory Appl 3(3):121–126

Wei Y-M, Liang Q-M, Fan Y et al (2006) A scenario analysis of energy requirements and energy intensity for China's rapidly developing society in the year 2020. Technol Forecast Soc Chang 73(4):405–421

World Bank (2010) World development indicators 2010. World Bank, Washington DC

Chapter 4
Residential Energy Consumption

Residential life in terms of final energy demand is an important aspect that has been increasingly influenced by consumer behavior under the premise of meeting the needs of basic shelter and food. Therefore, the analysis of residential energy consumption is an indispensable part of energy policy research. Different regions, including urban and rural areas, have distinctive energy consumption characteristics in terms of consumption levels and structures as a result of factors such as different economic prosperities, climate conditions, household incomes, and life habits, among others.

This chapter focuses on residential energy consumption and probes into the inherent laws and characteristics of residential energy consumption from various aspects, such as international comparisons, historical consumption features, the gap between urban and rural areas, and the discrepancy among regions. As China's urbanization process accelerates, along with the surge in the amount of energy consumption, to reasonably guide residential consumption behavior, this chapter quantitatively analyzes the influential factors of residential energy consumption in urban and rural areas, focusing on the following questions:

- What are the characteristics of residential energy consumption in the world's representative countries?
- What features of change are there in the total energy consumption and structure of China's residential sector?
- What are the differences in residential energy consumption between the urban and rural areas in China?
- What are the characteristics of residential energy consumption in each region of China?
- What are the critical influential factors of residential energy consumption in urban and rural areas?
- What implications can we draw to reasonably guide the behavior of China's residential energy consumption?

Y.-M. Wei and H. Liao, *Energy Economics: Energy Efficiency in China*,
DOI 10.1007/978-3-319-44631-8_4

4.1 Residential Energy Consumption Characteristics in Some Representative Countries

Residential energy consumption mainly refers to people's daily energy consumption related to their daily activities, such as heating, cooling, lighting, cooking, cleaning, and so on. Due to the differences in economic prosperity, residential lifestyles, climate conditions, population features, and energy policies among countries, residential energy consumption displays an even greater difference among these countries. This section comprehensively analyzes and compares the features of residential energy consumption in some of the world's representative countries from three dimensions: the structure of final energy consumption, the level of residential energy consumption, and the structure of consumption. By analyzing the features of the major countries' residential energy consumption, we hope to contribute towards the regulation of China's residential energy demand and the establishment of its energy economic policies, thereby realizing energy sustainable development for the country.

Data in this section mainly comes from the IEA (2009) and World Bank (2009). Energy consumption accounting defers from calorific value calculations. Energy is divided into six types: coal, petroleum, gas, biomass, electricity, and heating power. Few countries use renewable energy like wind and solar energy, and as this is limited; hence, it is not dealt with here. In addition, as residential private vehicle energy consumption falls under the category of the transportation sector (according to IEA), it will not be included in this section. The world's representative countries in this section include China, Canada, France, Germany, Japan, UK, US, India, Brazil, and Russia.

4.1.1 Final Energy Consumption Structure by Sector in Some Representative Countries

Regardless of whether or not it is a developed or developing country, the residential sector has always been an important component of a country's final energy consumption, constituting a relatively high proportion of total demand (as shown in Fig. 4.1). Taking 2006 as an example, the residential sector in most countries made up about 20–30 % of total final energy consumption. Among these countries, India was the highest at approximately 40.09 %, followed by China at 28.18 %. Therefore, it is of great importance to conduct research on China's residential energy consumption to achieve the national goals of energy saving and emission reduction.

The major developed countries have already completed the process of industrialization; thus, the percentage of industry in their national economic structures has been decreasing since then. Moreover, their industrial structures have transformed from labor-intensive to technology-intensive production, which has resulted in a gradual decline in the proportion of industrial energy consumption. Meanwhile, the tertiary sector has increasingly boosted their economies. Thus, the proportion of

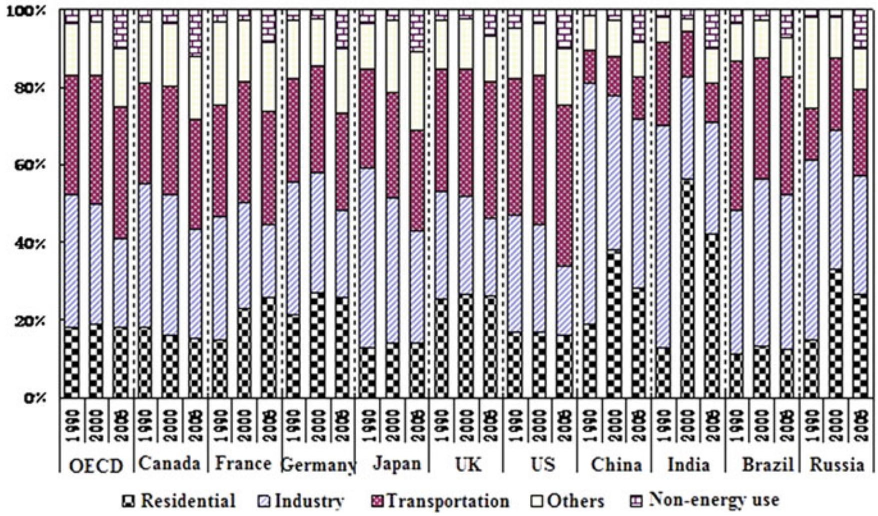

Fig. 4.1 Sectoral energy consumption in the OECD and representative countries (1990, 2000 and 2006)

energy consumption in the commercial transportation sector has steadily increased and this change has counteracted the corresponding decrease in industrial energy consumption. Moreover, while the advance in residential living standards has promoted more energy consumption, with household requests to further enhance their life styles, the residential energy consumption structure has become more efficient. Therefore, the proportion of the main developed countries' residential energy consumption has tended to stabilize, except for France, whose decrease in the proportion of industrial energy consumption has resulted in driving up the proportion of residential energy consumption from 13 to 27 %.

Developing countries in the process of industrialization not only need prosperous economies that promote their better living standards but also need to conserve resources in terms of sustainable development. The transformation of industrial structures, improvement of living standards, and improvement of energy consumption structures all influence the structure of the energy consumption sectors to different degrees. The proportion of the residential sector's energy consumption in the four developing countries fluctuated from 11 to 56 % during the 1990–2006 period. As shown in Fig. 4.1, the proportion of residential energy consumption in the developing countries rises at first and then falls. The reasons are as follows: it is apparent that the optimization of the industrial structure results in a decline in the proportion of energy consumption in the relatively energy-intensive industries, and in the meantime, the improvement of residential living standards results in an increase in the proportion of residential energy consumption; at the same time, when the proportion of industrial energy consumption is comparatively stable, the household requests for energy consumption to be cleaner and more efficient to improve their life quality leads to a decrease in the proportion of residential energy consumption.

4.1.2 Analysis of Trends in Residential Energy Final Demand for Some Representative Countries

Energy has become a necessity in the households' daily life; however, due to the differences among the countries in terms of their population, regional climates, lifestyles, and sector structures, there are differences in the total level of each country's residential energy consumption. Meanwhile, per capita residential energy consumption varies due to differences in the development stages.

4.1.2.1 Comparison of the Representative Countries' Total Residential Energy Consumption

Since 1980, the world's representative countries' total residential sector energy consumption has basically shown an upward trend (Fig. 4.2). Consider 2007 as an example. China and India have approximately 37 % of the world's population and

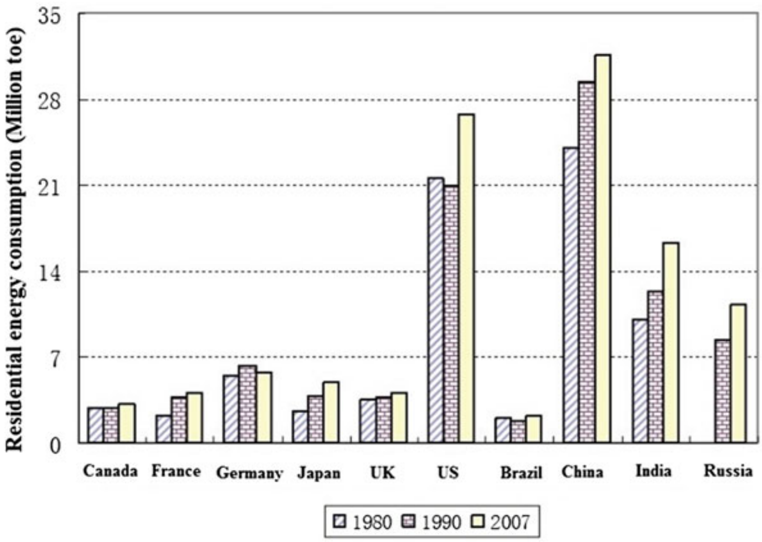

Fig. 4.2 Changes in the representative countries' total energy consumption (1980, 1990 and 2007)

in both countries, the rural residents consume a great deal of low-efficiency bio-energy; thus, these countries rank first and third, respectively, in terms of residential energy consumption. The US lifestyle shows a typical luxurious consumption pattern. Although its population makes up no more than a quarter of that of China, US residential energy consumption represents approximately 85 % of that of China. Influenced by its cold climate, Russian residents use a lot of energy for heating; moreover, its domestic energy resources are relatively abundant. Taken together, these factors lead to a high proportion of residential energy consumption. China, the United States (US), India, and Russia's total residential energy consumption far outweighs that of other countries. Among these four countries, China's residential energy consumption was 14 times that of Brazil while its population was only 6.5 times that of Brazil. The major reasons can be attributed to Brazil's geographical location in tropical and sub-tropical areas, reducing the need for winter heating. In addition, this result can also be attributed to its relative development stage and its relatively low residential living standard.

4.1.2.2 Comparison of the Representative Countries' Per Capita Residential Energy Consumption

As to the per capita index, which is influenced by the development stage, the world's representative countries' energy consumption per capita varies greatly. From Fig. 4.3, we can see that overall, the developed countries' energy consumption per capita is much higher than that of developing countries. Among the developed countries, the energy consumption per capita remains high, although that for Canada and the US has shown a declining trend from 1980 to 2007. The economic development level and climate characteristics of the UK, France, and Germany (the three Western European countries) are not very different, so their energy consumption per capita is similar. Japan's energy consumption per capita grew rapidly at an annual rate of 2.35 % from 1980 to 2007. However, compared with other developed countries, its energy consumption per capita is rather low. Russia's energy consumption per capita (an economy in transition) is much higher

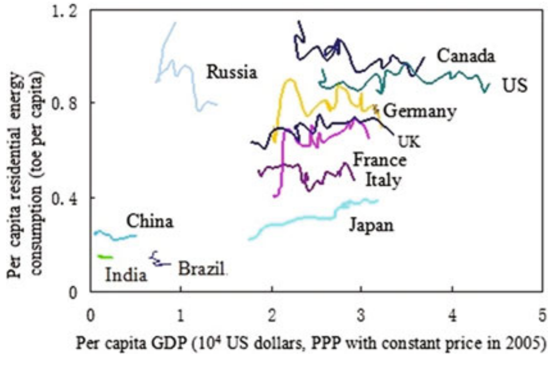

Fig. 4.3 Per capita GDP and per capita residential energy consumption of the representative countries during the 1980–2007 period (The date for Russia is from 1993 to 2007)

than that in developing countries and it is influenced by economic fluctuations, so the country's energy consumption per capita has displayed some dramatic downward fluctuations. Although both China and India's total residential energy consumption is very high, when it is divided by their large population, the countries' per capita levels are rather low, as these countries are restricted in terms of their development stage. Thus, their energy consumption per capita in 2007 was only 27 and 16 %, respectively, of that in the US. One can imagine that with ongoing economic development, the residential energy consumption in China and India will further increase. Brazil's energy consumption per capita is the lowest due to its relatively warm climate.

If we use GDP per capita to represent the different countries' economic development stage, then we know from Fig. 4.3 that there are considerable differences with respect to per capita energy consumption among developed or developing countries, or even among countries in the same development stage. For example, the developed and developing countries with a GDP per capita level of $30,000 have an energy consumption per capita ranging from 0.94 toe to 0.39 toe, of which the former is 2.4 times that of the latter. Moreover, China's residential energy consumption per capita is 64 % higher than that of India, even though both have a GDP per capita of approximately $2300. The climate factor does have an influence (e.g., Canada and China require much more winter heating), but the major reasons still pertain to lifestyle and consumption patterns. Therefore, it is necessary to reasonably guide the households' consumption patterns. Russia, an economic power in transition, is rather unique, as its GDP per capita is slightly higher than the developing countries, but its energy consumption per capita is much higher than the developing countries and even some developed countries. Russia's energy consumption per capita is 8.5 times that of Brazil, even though the GDP per capita level for both countries is $8200. Apart from the influence of climactic factors, Russia's consumption pattern is primarily to blame.

4.1.3 Comparison of the Energy Consumption Structure Among Representative Countries

As a result of the discrepancies in income levels, ease of energy acquisition, energy supply structure, and so on, countries vary greatly in terms of their final energy demand structure.

4.1.3.1 Changes in the Representative Residential Energy Consumption Structure

As developing countries, China, India, and Brazil all have a high percentage of rural population, a low income level, and a lack of efficient and clean energy. As a result, traditional biomass energy (straw, firewood, etc.) continues to be an important fuel for rural residents. Thus, biomass energy occupies a high proportion of the developing countries' total energy consumption. Because the efficiency of traditional biomass energy is quite low, the extensive use of such energy results in a consistently high proportion of China and India's total energy consumption.

Accordingly, after the developed countries have completed the industrialization process and have achieved a high level of residential income, their energy supply structures mainly comprise clean and efficient commercial energy fuels that have relatively big differences from the developing countries. In 2007, oil products, natural gas, and electricity clean and efficient energy added up to 80 % of the developed countries' residential energy consumption, whereas biomass energy took up approximately 40–80 % of the developing countries' residential energy consumption. However, as a consequence of differences in the natural advantage of energy sources and resources, the developed countries' residential energy consumption sources are slightly different. The UK's residential energy is mainly natural gas, occupying approximately 65 % of the total demand. Japan's residential energy consumption structure consists of oil, natural gas, and electricity, of which electricity constitutes the biggest share at more than 50 % (Fig. 4.4). Thus, Japan's comparatively low level of energy consumption per capita essentially lies in its clean and efficient energy consumption structure.

In both developed and developing countries, the residential sector's energy consumption structure has become more optimal since 1980. Clean as well as efficient, natural gas and electricity have constituted an increasingly higher proportion of residential final demand. For example, the total percentage of electricity

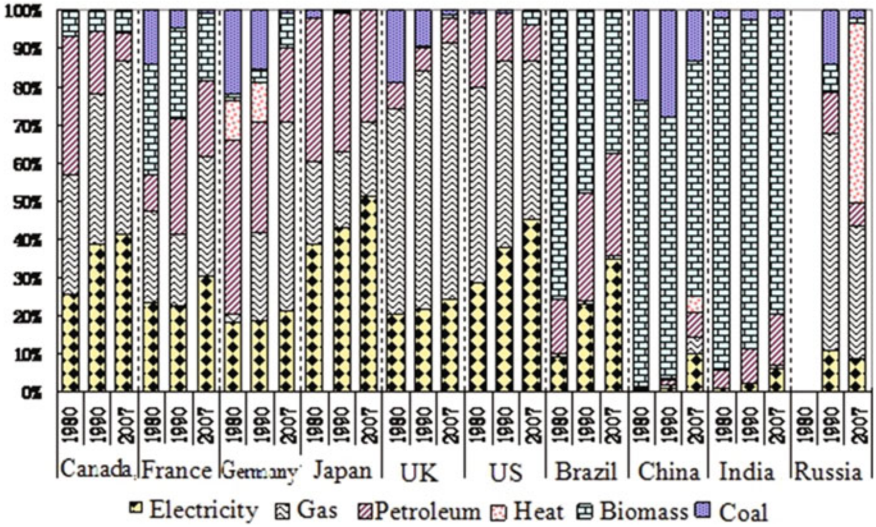

Fig. 4.4 Change in the residential energy consumption structure of the representative countries (1980, 1990 and 2007)

and natural gas in meeting Canada and Germany's residential energy demand increased 30 and 50 % points, respectively, from 1980 to 2007 (Fig. 4.4). In contrast, the percentage of coal used for residential energy consumption has been gradually declining in every country. For example, coal use in China and Russia decreased by seven and 12 % points, respectively, in the same period. On the one hand, the optimization of residential energy consumption boosts the energy efficiency of final demand. On the other hand, it alleviates the pollution problem and improves the residents' living environment. Biomass energy, which is a kind of renewable energy, includes traditional biomass energies such as straw and firewood, and clean energies, like methane. Because different countries have had different biomass energy policies in different periods, the percentage change in the proportion of biomass energy in terms of a country's energy consumption structure is also different.

4.1.3.2 Representative Residential Energy Changes Towards Low-Carbon Development

Since 1980, the carbon emissions from the residential sector have displayed certain characteristics according to the economic development of each country. Despite the fact that the problem of environmental and greenhouse gas emissions has mainly resulted from the residents' daily behavior, along with the enhancement of their living standards, the quality of the energy sources to meet final demand is improving as residential energy consumption is increasingly cleaner and consisting of low-carbon energy fuels. From the correlation between each country's GDP per capita and their residential sector's carbon emissions (Fig. 4.5), we can see that if carbon emissions per unit of energy (the carbon emissions coefficient) are used to measure the residential sector's carbon emissions level, both the developed and developing countries' carbon emissions levels show a sharp decline. Among these countries, China is the most significant as its carbon emissions coefficient decreased approximately 16.5 % from 1980 to 2007. However, compared with the developed

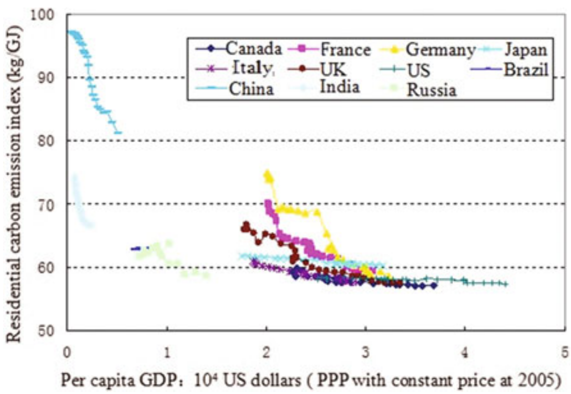

Fig. 4.5 Relationship between per capita GDP and per caption residential carbon emissions in the representative countries during the 1980–2007 period (Only commercial energy is considered)

countries, the developing countries' residential carbon emissions coefficients are still very high, especially China and India, whose coefficients are 40 and 16 % higher, respectively, than that of US. Generally speaking, every country's residential energy consumption structure has been evolving into a low-carbon environment, whereas the developing countries' carbon emissions coefficients are relatively high and still have room for considerable improvement.

4.1.4 Regional Comparison of Residential Energy Consumption

Through the comparative analysis of the representative countries' residential energy consumption, we find the following:

(1) The residential sector has become important in terms of final energy demand in every country. The percentages of residential energy consumption in the developed countries have remained steady, whereas those in the developing countries have fluctuated from up at first to then down.
(2) The absolute amounts of the different countries' residential energy consumption have varied greatly. Restricted by the development stage, there are huge discrepancies in per capita energy consumption, even for countries at the same development level, as a result of differences in the consumption pattern. Overall, per capita energy consumption in the developed countries is approximately three times higher than that in the developing countries.
(3) The residential energy consumption structure varies between developed and developing countries. The developed countries mainly focus on electricity, oil, and gas, whereas the developing countries focus much more on traditional bio-energy. With the improvement in living standards, the residential energy consumption structure of both developed and developing countries is evolving into a high efficiency and low-carbon environment.

4.2 State of China's Residential Energy Consumption

In China, the amount of energy consumed by its residents is second only to that of industry. Therefore, residential energy consumption draws a lot of attention, especially in terms of accelerating urbanization and building a better, all-round society. As a result of the improvement in living standards, the amount and quality of energy is higher than before. Therefore, the characteristics of residential energy consumption in China will be analyzed in this section and we hope that our analysis can be of some help in making future policy on energy consumption.

Unless otherwise noted, the energy data in this chapter are calculated using calorific value calculations. The original data are from the *Comprehensive Statistical Data and Materials on 50 Years of New China* and the *China Energy Statistical Yearbook*. Provincial energy data are transformed from physical quantities into standard quantities using the transformation coefficients in the *Energy Balance of China*.

4.2.1 Change in Residential Energy Consumption

Great changes have taken place in energy consumption in China since the reform and opening-up period; in this section, the level of residential energy consumption (excluding non-commercial energy) from 1980 to 2007 will be discussed according to the statistical data available.

4.2.1.1 Growth in the Total Amount of Residential Energy Consumption

With the development of the economy, the living standards of the Chinese people are improving and the amount of residential energy consumption is increasing as well (Table 4.1). The total amount of residential energy consumption rose from 98.53 million tons of coal equivalent (tce) in 1980 (NBS-DITS 1998) to 267.897 million tons in 2007 (NBS-DITS and NDRC-BE 2009). The average annual growth rate is 3.74 % and since 2002, the annual growth rate has been as high as 7.33 %.

As far as residential energy consumption per capita is concerned, it has been increasing rapidly in China, growing from 97.7 kg of coal equivalent (kgce) in 1980 to 203.3 kgce in 2007, and the average annual growth rate is approximately 3.8 %. The amount of residential energy consumption per capita is an important index of the consumption level and quality of life. The growth in residential energy consumption per capita in China reflects not only the improvement in living standards of the Chinese people and the achievements in building a well-off society but also shows that the consumption pattern of the Chinese people is still not being economized in terms of energy savings and conservation.

Rapid growth of China's economy, together with the acceleration of urbanization and the formation of a well-off society means an improvement in the living standards of the Chinese people. Therefore, on the one hand, residential energy consumption must increase continuously; on the other hand, environmental problems caused by energy consumption become more prominent. For instance, an excessive amount of carbon dioxide emissions will aggravate the problem of global warming. So, the energy conservation potential in the residential sector in China is tremendous and guiding the people in their everyday activities and advocating consumption patterns that are economizing are effective ways of saving energy and reducing emissions.

Table 4.1 The amount of total energy consumption and residential energy consumption(1980–2007)

Year	Total energy consumption (10^8 tce)	Residential energy consumption (10^8 tce)	Per capita residential energy consumption (kgce)	Year	Total energy consumption (10^8 tce)	Residential energy consumption (10^8 tce)	Per capita residential energy consumption (kgce)
1980	6.03	0.96	97.70	1994	12.27	1.54	129.30
1981	5.94	1.01	101.30	1995	13.12	1.57	130.80
1982	6.21	1.03	102.30	1996	13.89	1.77	145.50
1983	6.60	1.09	106.60	1997	13.82	1.64	133.10
1984	7.09	1.18	113.50	1998	13.22	1.44	115.90
1985	7.67	1.33	127.50	1999	13.38	1.52	121.45
1986	8.09	1.36	127.30	2000	13.86	1.60	126.44
1987	8.66	1.43	132.10	2001	14.32	1.66	130.27
1988	9.30	1.55	141.00	2002	15.18	1.75	136.89
1989	9.69	1.56	139.30	2003	17.50	1.98	153.89
1990	9.87	1.58	139.20	2004	20.32	2.13	164.19
1991	10.38	1.60	138.10	2005	22.47	2.35	179.90
1992	10.92	1.56	133.40	2006	24.63	2.54	194.73
1993	11.60	1.57	130.60	2007	26.56	2.68	203.28

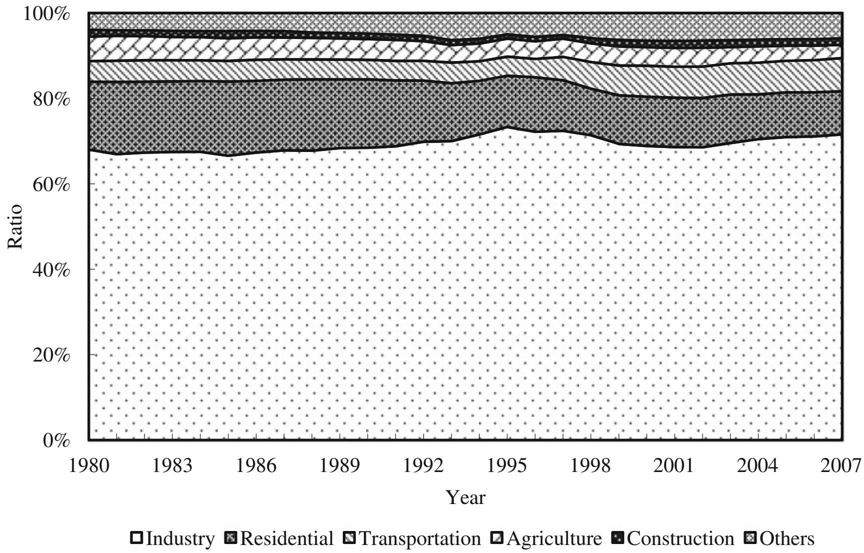

Fig. 4.6 Shares of energy consumption in China by sector (1980–2007). *Data sources* NBS-DITS (2009), NDRC-BE (2009), NBS-DITS (2001) and authors' calculations

4.2.1.2 Reduction in the Share of Residential Energy Consumption

The development of China's economy in recent years has led to an increase in the total amount of energy consumption. As a result, the proportion of residential energy consumption has decreased relative to the total amount of energy consumption (Fig. 4.6). According to NBS-DITS (2009), NDRC-BE (2009), NBS-DITS (2001), as well as our calculations, we find that the proportion of residential energy consumption has been in a downward trend relative to the total amount of energy consumption since 1980 and that there has been a significant decline since 1990, where the proportion has decreased from 16.01 % in 1990 to 10.09 % in 2007.

4.2.2 Analysis of Different Kinds of Energy Consumption

According to the classification from the National Bureau of Statistics of China, residential energy in this section is classified as coal (including raw coal, clean coal, other washed coal, and briquette coal), petroleum products (including gasoline, kerosene, diesel oil, and liquefied petroleum gas), natural gas, heat, electricity, and other energy (coke, coal gas, and other coking products). The residential energy consumption structure (excluding non-commercial energy) refers to the proportion

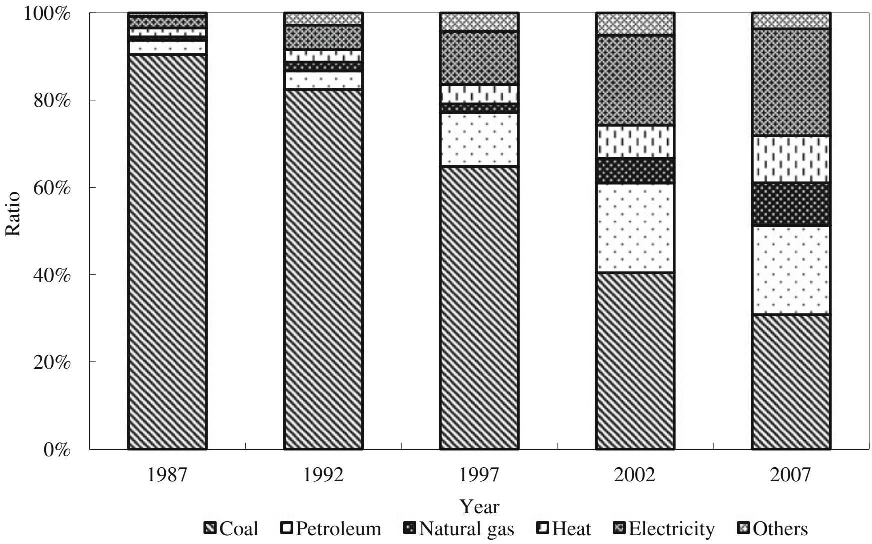

Fig. 4.7 Residential energy consumption structure in China, 1987–2007. *Data sources* NBS-DITS (1990, 1998, 2001), NBS-DITS, NDRC-BE (2003), NBS-DE, NBE-DCS (2009) and authors' calculations

of the different energy resources to the total amount of energy consumption.[1] Here, we analyze the consumption of different forms of residential energy in terms of the changes in their consumption structures and consumption levels.

4.2.2.1 Transformation in the Residential Energy Consumption Structure

Because of changes in the consumption structure of primary energy, improvements in technology, greater environmental awareness, and so on, the final energy consumption structure is always optimizing, including the consumption structure of residential energy in China. According to NBS-DITS (1990, 1998, 2001), NBS-DITS and NDRC-BE (2003), NBS-DE and NBE-DCS (2009), and our calculations, the consumption of solid fuels, such as coal, which is an important source of pollution in residential energy and total final energy demand, is on the decline. In 1987, coal consumption contributed 90 % of the total amount of residential energy consumption while in 2007, the percentage fell to 30 % (Fig. 4.7). The consumption of clean energy, such as electricity and heat, and high-quality energy, such as petroleum and natural gas, increased rapidly. Until 2007, the amount of consumption from electricity, heat, and natural gas accounted for 45 % of total

[1]Note: The classification of energy is different from Sect. 4.1.

residential energy consumption, which shows that the consumption structure of residential energy consumption was trending toward higher quality and lower carbon fuels. Overall, the residential energy consumption structure is no longer coal-based but has become more diversified and of higher quality.

Changes in the residential energy consumption structure show that economic development brings great improvement to the people's living standards, infrastructure, everyday activities, and consumption behaviors. For example, refrigerator ownership in urban areas was 40.22 per one hundred households in 1990 while by 2007, the number had more than doubled to 95.3 per one hundred households (NBS 2008). With the development of electrification in China, electricity consumption also increased year-on-year.

4.2.2.2 Changes in the Consumption Level of Different Resources for Residential Energy

Transformation in the structure of residential energy consumption is caused by changes in the amount of consumption of different forms of energy. According to NBS-DITS (1990, 1998, 2001), NBS-DE and NBE-DCS (2009), and our calculations, we get Fig. 4.8, showing the five sources of energy that were mainly used by residents in China from 1986 to 2007, where the amount of coal consumption decreases but the change curve is unstable. There is a remarkable drop from 1996 to

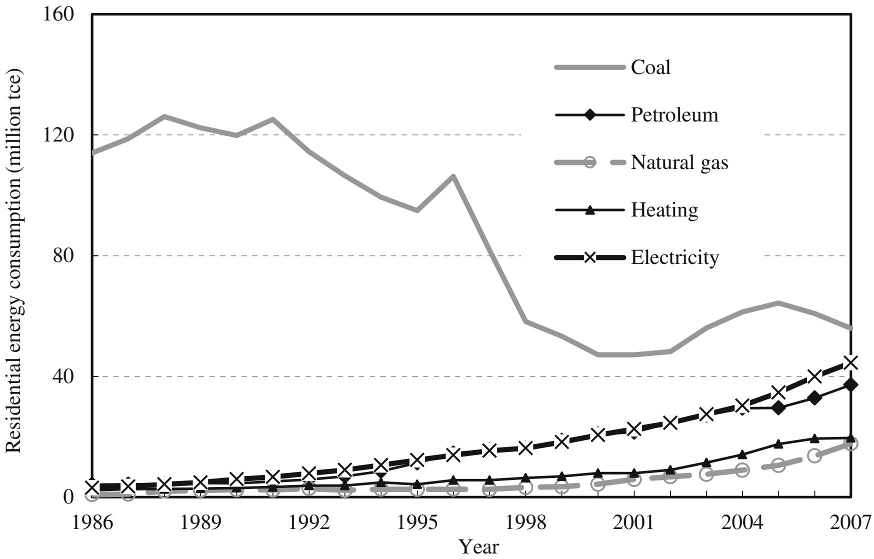

Fig. 4.8 Changes in the kinds of energy consumed by the residential sector in China (1986–2007). *Data sources* NBS-DITS (1990, 1998, 2001), NBS-DE, NBE-DCS (2009) and authors' calculations

2000 while the amount of coal consumption increases from 2000 to 2005 then decreases again. The amount of consumption of other forms of energy grows steadily, where petroleum, natural gas, heat, and electricity consumption are 3723.46, 1774.04, 1967.19, and 4452.31 ten thousand tce, respectively. Compared with 1987, the increases were 11, 15, 10, and 13 % during the two decades, among which the growth of electricity and petroleum consumption was rapid and that of heat and natural gas was relatively slow. Although the gap between the consumption of coal and that of other forms of energy has narrowed, coal still accounts for a large proportion, so the residential energy consumption structure needs further optimization in the future. Increasing the proportion of high-quality energy in residential energy consumption is an effective way of improving energy efficiency and living standards. In addition, there are various reasons leading to the significant decrease in the amount of coal consumption from 1997 to 2000, such as the Asian financial crisis between 1997 and 1998, the growth in electricity consumption as a substitution for coal, the possible inaccuracy of coal consumption in the statistical data, and so on.

4.2.3 Characteristics of the Residential Energy Consumption

(1) With the development of the society and economy, including living standards, the total amount of energy consumption has increased year-on-year. Moreover, China's sustained economic growth, together with the acceleration of urbanization, will ensure that energy consumption increases for some time to come.
(2) Although the total amount of residential energy consumption is increasing, its proportion of total energy consumption in the country is decreasing, which is a result of the long-existing energy consumption pattern of "production comes first and living standards follow."
(3) The residential energy consumption structure has improved significantly since the reform and opening-up period in which the proportion coal consumption has decreased from 90 to 30 % while that of clean energy has increased. However, because of resource limitations, the residential energy consumption structure still needs further optimization.

4.3 Comparison Between Urban and Rural Residential Energy Consumption

The dual economic structure is a typical characteristic of the Chinese national economic system, and levels of economic development and quality of life are very different between the urban and rural areas. Therefore, specific research into the

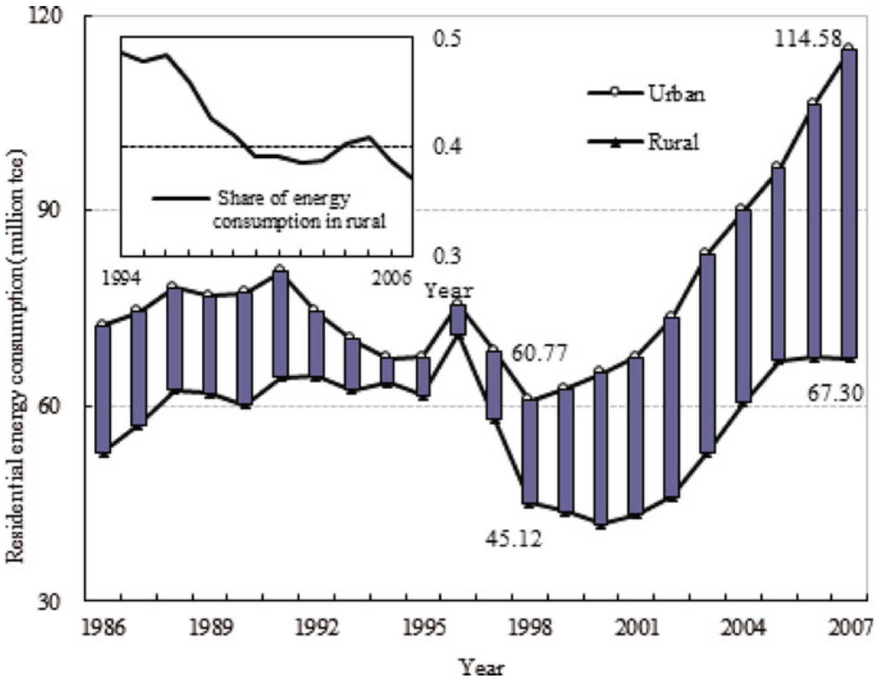

Fig. 4.9 Residential energy consumption in the urban and rural areas of China (1986–2007). *Data sources* NBS-DITS (1990, 1998, 2000, 2001), NBS-DITS, NDRC-BE (2005, 2006, 2007), NBS-DE, NBE-DCS (2008, 2009) and authors' calculations

features, levels, and structure of energy consumption in China is of great significance in balancing urban and rural development, building-up the rural areas, and integrating the economic and social development of the urban and rural areas. Because of a lack of statistical data before 1986, we investigate the energy consumption in the urban and rural areas from 1986 to 2007, according to NBS-DITS (1990, 1998, 2001), NBS-DITS and NDRC-BE (2005, 2006, 2007), NBS-DE and NBE-DCS (2008, 2009), and our own calculations. The results are shown in Figs. 4.9, 4.10, 4.11, and 4.12.

4.3.1 *Differences Between Urban and Rural Residential Energy Consumption*

Differences in residential energy consumption per capita reflect the gap in social development between the developing and developed countries, as well as the gap between the urban and rural areas in China. Narrowing the gap is one of the key problems to solve in building a well-off society in an all-round way.

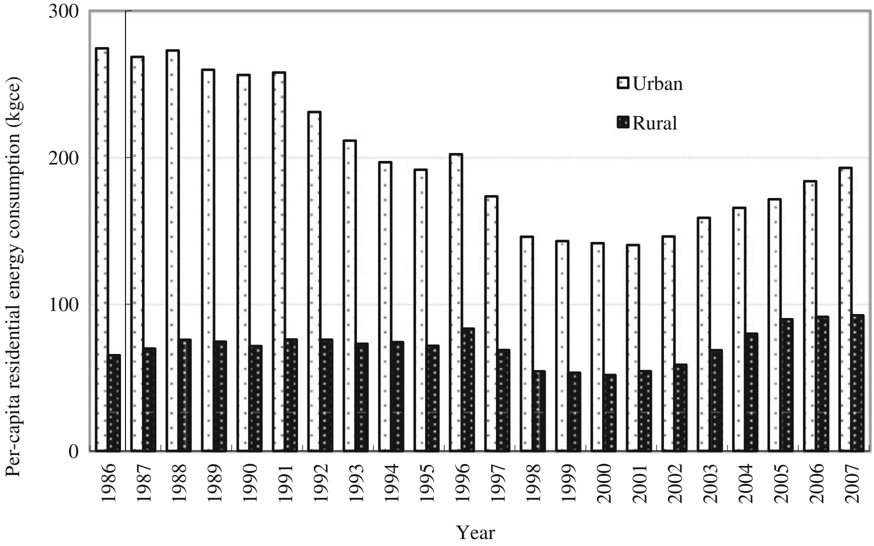

Fig. 4.10 China's urban and rural per capita energy consumption levels (1986–2007). *Data sources* NBS-DITS (1990, 1998, 2000, 2001), NBS-DITS, NDRC-BE (2005, 2006, 2007), NBS-DE, NBE-DCS (2008, 2009) and authors' calculations

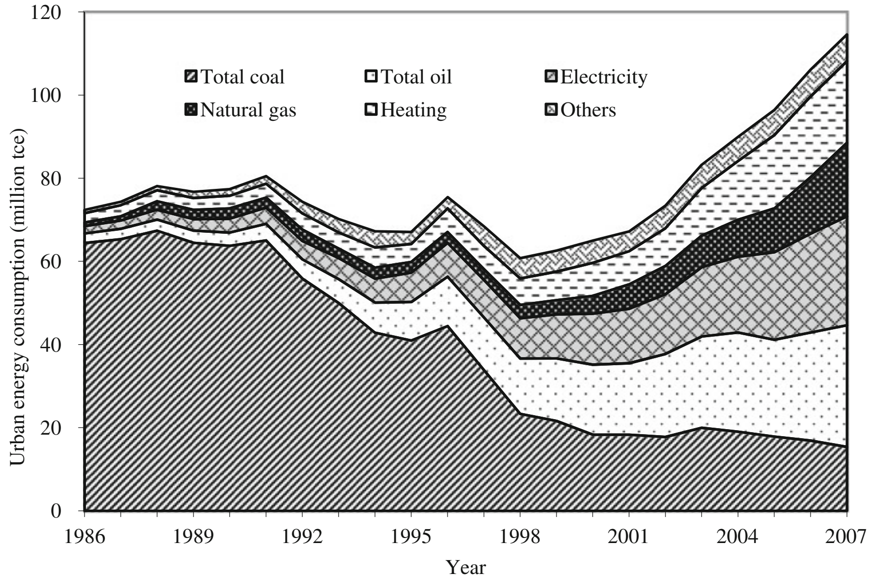

Fig. 4.11 Structural changes in residential energy consumption in the urban areas of China (1986–2007). *Data sources* NBS-DITS (1990, 1998, 2000, 2001), NBS-DITS, NDRC-BE (2005, 2006, 2007), NBS-DE, NBE-DCS (2008, 2009) and authors' calculations

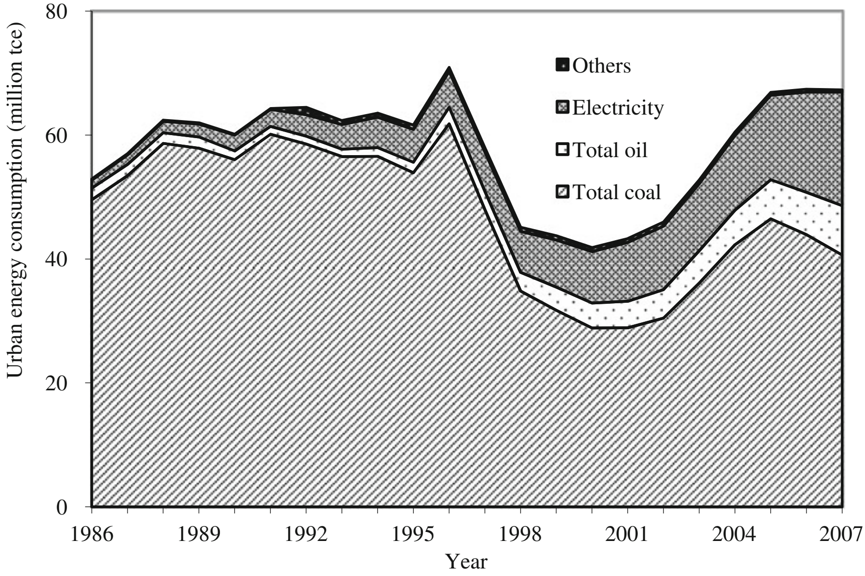

Fig. 4.12 Structural changes in the residential energy consumption of rural areas in China (1986–2007). *Data sources* NBS-DITS (1990, 1998, 2000, 2001), NBS-DITS, NDRC-BE (2005, 2006, 2007), NBS-DE, NBE-DCS (2008, 2009) and authors' calculations

Figure 4.9 shows the changes in energy consumption of the urban and rural residents from 1986 to 2007. We find that energy consumption decreased from 1997 to 1999. There are a variety of reasons accounting for this phenomenon, but it is in accordance with the negative correlation between economic development and energy consumption (Wei et al. 2008). Except for this three-year period, residential energy consumption in China has always been increasing since the reform and opening-up period, especially for urban areas, where it has grown faster than the rural areas, and the average annual growth rate has reached 7 % in the most recent ten-year period. By 2007, the residential energy consumption in urban areas accounted for 63 % of the total in China. The decreasing proportion of residential energy consumption in rural areas (upper-left corner in Fig. 4.9) shows that the gap in energy consumption between urban and rural areas is increasing. The following data also illustrates this point. The residential energy consumption has increased from 105.88 million tce in 1998 to 1818.8 million tce in 2007 (NBS-DE and NBE-DCS 2009; NBS-DITS 2001), where the urban residents accounted for 53.81 million tons and rural residents accounted for 22.18 million tons. The amount of urban consumption was 2.43 times that of rural consumption.

As to the residential energy consumption per capita, there are significant differences between the urban and rural areas, as shown in Fig. 4.10. We can see from the figure that the amount of residential energy consumption per capita in the urban areas in 1986 reaches 274.5 kgce, which is four times greater than that of the rural areas. Although the number decreases to 140.4 kgce in 2001 and the gap between the two narrows, it is still 2.6 times the consumption in rural areas. But since 2001, the residential energy consumption per capita in the urban areas increases quickly and the inequality in consumption grows too. Moreover, the inequality gets worse after 2005 because of the slow growth in residential energy consumption in the rural areas. Therefore, guiding the people's way of life in terms of consumption, especially urban households, is necessary in the process of accelerating urbanization and building new infrastructure in the rural areas so as to construct a more economical and homogeneous society.

4.3.2 Differences Between the Structure of Urban and Rural Residential Energy Consumption

Both the amount and quality of energy consumption by urban and rural residents differ greatly. Figures 4.11 and 4.12 show the changes in the residential energy consumption structure in the urban and rural areas, respectively.

4.3.2.1 Structural Changes in Residential Energy Consumption in the Urban Areas

Energy is mainly consumed in the urban areas and research into the existing problems in terms of the consumption structure is of great significance in improving the current situation of energy utilization in China, stimulating the use of clean energy, increasing energy efficiency, saving energy, and reducing emissions.

As shown in Fig. 4.11, the proportion of coal consumption to total residential energy consumption in the urban areas has been decreasing since 1986, from 89 % in 1986 to 13 % in 2007. Natural gas, heat, and electricity have been the main sources of household energy and they have contributed to more than half of the total energy consumption. As a result, the energy consumption pattern has transformed from coal-based fuels to clean energy-based fuels. At present, the type and number of household appliances in urban households is increasing every year. Moreover, household appliances, such as washing machines and TV sets, air conditioners, computers, and microwave ovens, are owned by more and more families; for example, the number of computers has risen from 9.7 per one hundred families in 2000 to 53.8 per one hundred families in 2007 (NBS 2008), which has contributed to the growth in electricity consumption in urban households. This result is also shown in Fig. 4.11.

4.3.2.2 Changes in Residential Energy Consumption in Rural

Building a modern rural society was proposed in China in 2006 and the development of the household energy used in the rural areas plays an important part in building that society. A scientific analysis of rural energy consumption is of great significance in realizing the strategic targets of rural development, building a resource-saving and environmentally friendly society, and setting policies on energy development.

We can see from Fig. 4.12 that the changes in the energy consumption structure in rural areas are different from those in the urban areas. Although the proportion of coal consumption to the total residential energy demand decreases gradually and that of petroleum and electricity increases accordingly, coal is still the main energy used in rural areas and clean energy, such as heat and natural gas, account for only a small part of the total. In 2007, coal, electricity, oil, and other energy sources contributed 60.39, 27.23, 11.84, and 0.54 %, respectively, of the total amount of energy consumption in rural areas. The relatively large amount of coal used in final demand has many disadvantages, such as a low energy efficiency and a high pollution threshold. Therefore, the energy consumption structure of rural residents can be optimized.

Consumption of high-quality clean energy in rural China has increased rapidly since the reform and opening-up period. The amount of clean energy consumption in the rural areas was 3.1522 million tce in 1986, which accounted for 6.0 % of the total amount while in 2007, the consumption increased to 26.2905 million tce and accounted for 39.1 % of the total amount. The fast growth in clean energy consumption in the rural areas shows that the living standards in the countryside are improving. At present, coal is the main fuel used for heating and cooking, but its utilization efficiency ratio as a household energy source is very low—the thermal efficiency of coal is only about 30 % (Wei et al. 2006). Coal's low utilization efficiency ratio leads to a lot of waste, severe environmental pollution, and emissions of greenhouse gases. Therefore, improving the quality of household energy in rural areas should be the key point in the process of building a modern rural society.

4.3.2.3 Comparison of Residential Energy Consumption Between Urban and Rural Areas

Figures 4.13 and 4.14 were based on NBS-DE, NBE-DCS (2009) and our calculations. We clearly recognize the residential use of energy in the urban and rural areas from Fig. 4.13. At present, the structure of residential energy consumption is unbalanced because the coal consumption in rural areas is 2.65 times that in urban areas while oil consumption in the urban areas is 3.67 times that in the rural areas. In terms of electric power consumption, there is also a difference between the urban and rural areas. The amount consumed in urban areas is 1.45 times as much as in rural areas. In addition, some sources of energy, such as natural gas and heat, are only supplied in urban areas. The analysis above shows that the distribution of

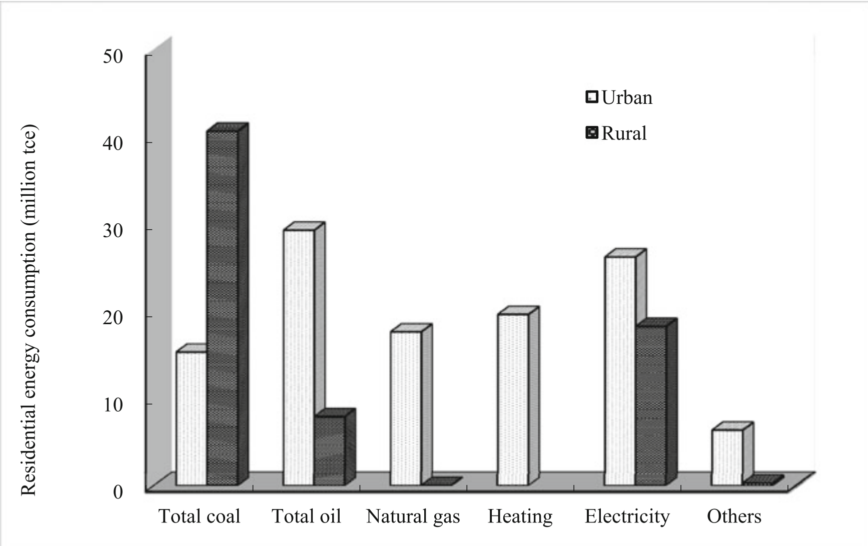

Fig. 4.13 Residential energy consumption in the urban and rural areas of China (2007). *Data sources* NBS-DE, NBE-DCS (2009) and authors' calculations

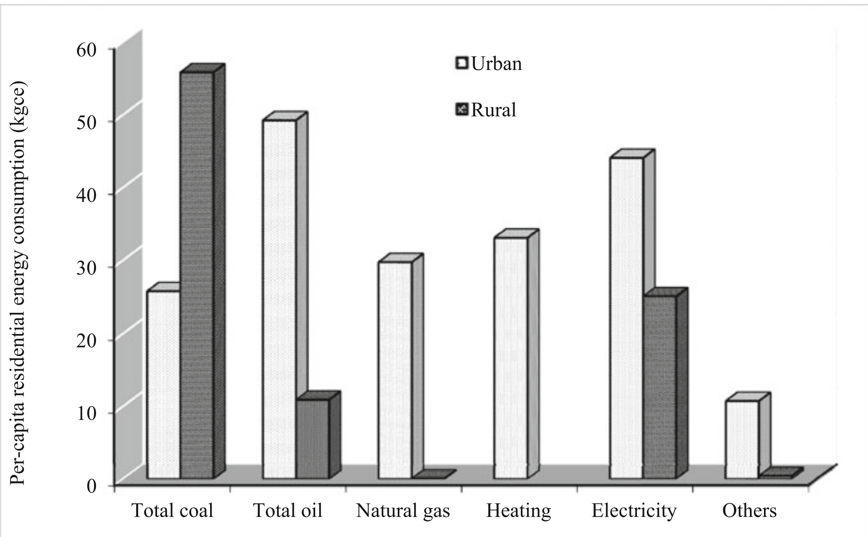

Fig. 4.14 Residential energy consumption per capita in the urban and rural areas of China (2007). *Data sources* NBS-DE, NBE-DCS (2009) and authors' calculations

energy in urban and rural areas is unbalanced, and the quality of energy used in rural areas is relatively poor. Therefore, there is still a long way to go to optimize the structure of residential energy consumption, especially in rural areas.

Because the number of rural residents is greater than the number of urban residents (the former is 1.23 times the latter), there are differences between residential energy consumption per capita and the total amount of consumption. Compared with the difference in total consumption, the difference in residential energy consumption per capita between the urban and rural areas is not that obvious while the differences in the consumption of petroleum, natural gas, and electricity are increasing (Fig. 4.14). For example, petroleum and electricity consumption per capita in the urban areas are 4.50 and 1.75 times that in rural areas, respectively, and the difference in the amount of natural gas consumption is much greater than the former two energy sources. Although the difference in total coal consumption per capita is not that big when compared with consumption in the past, it is still 2.16 times that in urban areas.

Based on the research into the residential energy consumption levels and structures in urban and rural areas and our comparison of the energy consumption status between urban and rural areas, we make the following conclusions:

(1) Since 1986, both the residential energy consumption per capita and total amount of consumption in the urban and rural areas are on the rise. Although the difference in the residential energy consumption level between the urban and rural areas is decreasing, the difference is still there; in particular, the gaps in the residential energy consumption per capita and total amount of consumption between the urban and rural areas have widened in recent years.
(2) The structure of residential energy consumption and quality of the energy consumed in the urban and rural areas have improved since 1986, where the residential energy consumed in the urban areas has transformed from coal-based to cleaner energy-based fuels while coal is still the main residential energy source in rural areas.
(3) The main factors that influence the structure of residential energy consumption in the urban and rural areas are the imbalance in the availability of energy and infrastructure, as well as the price variations of difference sources of energy.

4.4 Regional Comparison of Residential Energy Consumption

There are considerable differences among the configuration of regional resources, level of economic development, economic structure, as well as household lifestyles, resulting in differences in the regional energy consumption and consumption structure. Therefore, we conduct a comparative analysis of the energy consumption in different areas of China. We divide 31 provinces, municipalities, or autonomous

Table 4.2 The eight regional divisions, including provinces

Region	Province	Region	Province
Northeast region (A)	Heilongjiang, Jilin, Liaoning	Southern coastal region (E)	Fujian, Guangdong, Hainan
Beijing–Tianjin region (B)	Beijing, Tianjin	Central region (F)	Shanxi, Henan, Anhui, Hubei, Hunan, Jiangxi
Northern coastal region (C)	Hebei, Shandong	Northwest region (G)	Inner Mongolia, Shaanxi, Ningxia, Gansu, Qinghai, Xinjiang
Eastern coastal region (D)	Jiangsu, Shanghai, Zhejiang	Southwest region (H)	Sichuan, Chongqing, Yunnan, Guangxi, Guizhou, Xizang

Due to no data for Tibet in *China's Energy Statistics Yearbook*, the divisions do not include Tibet

regions into eight regions. The divisions are according to geographical location, natural resources, social and cultural background, economic development level, and inter-regional economic linkages and based on the division standards of the State Information Center (2005). The eight regions are presented in Table 4.2.

In 2007, the GDP per capita for the Beijing–Tianjin region was more than 50,000 yuan (RMB) and household energy consumption per capita reached 443 kgce while the GDP per capita in the eastern coastal region was 39,000 yuan and household energy consumption per capita was 144 kgce. Assume that China's regional GDP per capita in the next 20 years will reach the current level of the Beijing–Tianjin region. According to the standard of the Beijing–Tianjin region, China's domestic energy consumption will reach 57.44 million tce, but according to the standard of the eastern coastal region, the residential energy consumption will be only 25.12 million tce. The difference between the two numbers is more than double. The demand for residential energy based on the different consumption patterns of different regions is very distinct, so it is extremely important to study the regional level of development and energy consumption patterns and then to determine the combined energy consumption patterns for the whole country, so to study the regional level of development and energy consumption patterns and then to determine the energy consumption patterns in the whole country has a great significance in realizing the sustainable development of energy and environment.

4.4.1 Regional Comparison of Residential Energy Consumption

The imbalance in development of the different areas in China directly results in the household differences in living conditions and consumption levels and in the residential energy consumption levels. In the following discussion, we focus on two indicators—the total residential energy consumption per capita and the energy consumption per capita—to compare the similarities and differences of residential energy consumption among regions. The resource data are based on NBE-DCS (2009) and on our calculations.

4.4.1.1 A Comparison of Total Residential Energy Consumption Per Capita in Different Regions

As shown in Fig. 4.15, the residential energy consumption per capita in various regions of the country is very different (the dotted line refers to the national mean value of energy consumption per capita). The residential energy consumption per capita in the Beijing–Tianjin region has the highest level of 443.09 kgce, which is 2.7 times the national average, followed by the northeast region at 264 kgce, which is 1.6 times the national average. The northwest region is 217.91 kgce, which is slightly higher than the national average while the consumption in the northern and southern coastal regions is the same as the national average. The consumption in the eastern coastal region, central region, and southwest region is approximately 100–150 kgce, which is below the national average.

The GDP per capita also varies by region. The Beijing–Tianjin region is the highest, followed by the eastern coastal region and southern coastal region. The northern coastal and northeast regions are average while the central region and northwest and southwest regions are below average (Fig. 4.15). Comparing the regional GDP per capita and the residential energy consumption per capita, the Beijing–Tianjin region is the highest in both categories while the central and southwest regions are the lowest in both categories. However, among the eight regions, there is not a high correlation between GDP per capita and residential energy consumption per capita (i.e., where energy consumption is high, GDP per

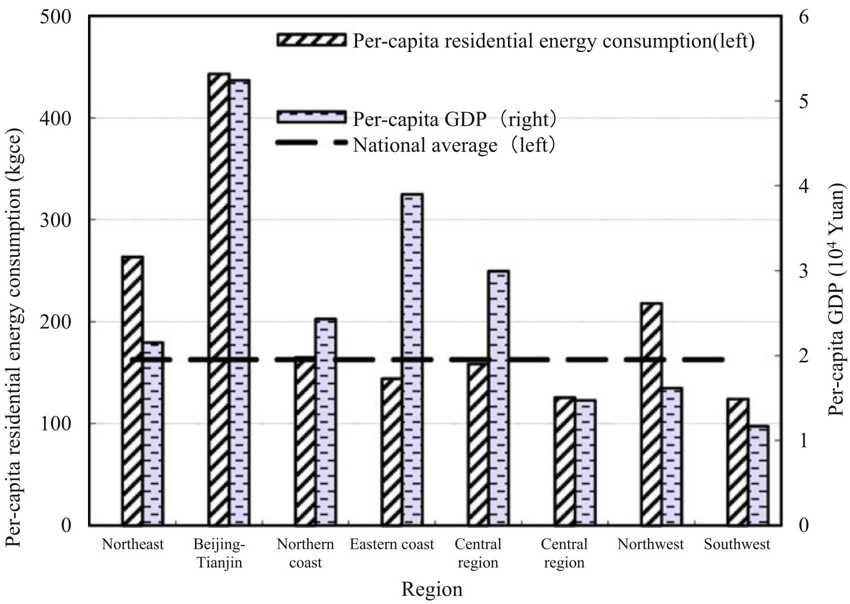

Fig. 4.15 Comparison of energy consumption per capita and GDP per capita in different regions (2007). *Data sources* NBS-DE, NBE-DCS (2009) and authors' calculations

capita is also high and vice versa). For example, GDP per capita of the eastern coastal region is just below that of the Beijing–Tianjin region, but its residential energy consumption per capita is one of the lowest among regions. The cause of this gap between the categories will be discussed later.

4.4.1.2 A Comparison of Residential Energy Consumption in Different Regions

Specifically, the energy consumption in different regions also showed significant differences (Fig. 4.16).

(1) Residential coal consumption per capita: the consumption in the Beijing–Tianjin region and northwest region is significantly higher than the national average, followed by the northern coastal, central, northeast, and southwest regions, respectively, at the national average. The consumption in the eastern coastal and southern coastal regions is very low, at 23 and 19 % of the national average, respectively.

(2) Residential oil consumption per capita: the consumption in the Beijing–Tianjin region is the highest, at 3.59 times the national average. The consumption in the southern coastal region, eastern coastal region, and northeast

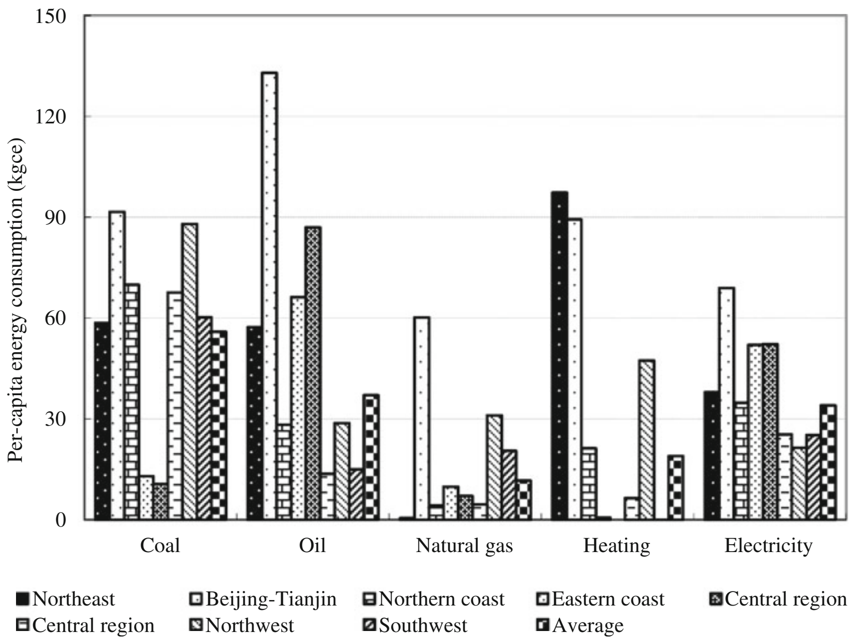

Fig. 4.16 Differences in residential energy consumption by region (2007). *Data sources* NBS-DE, NBE-DCS (2009) and authors' calculations

region is also relatively high, at 2.35 times, 1.79 times, and 1.54 times the national average. The consumption in the northwest and northern coastal regions is slightly lower than the national average, at 76 and 77 % while the consumption in the southwest and central regions is very low, at 37 and 40 % of the national average, respectively.

(3) Residential natural gas consumption per capita: the consumption per capita in the Beijing–Tianjin region is much higher than that in other regions, at 5.18 times the national average. The consumption in the northwest and southwest regions is also higher, at 2.67 times and 1.76 times the national average, respectively. The consumption in the eastern coastal, southern coastal, central coastal, and northern coastal regions is below the national average, at 85, 61, 39, and 37 % of the national average, respectively. People in the northeast region use little natural gas at only 4 % of the national average.

(4) Residential heat consumption per capita: in the northeast and Beijing–Tianjin regions, the consumption is very high, at 5.14 times and 4.72 times the national average, respectively. In the northwest and northern coastal regions, the consumption is also relatively high, at 2.50 times and 1.12 times the national average, respectively. The consumption in the central region is below average, or 34 % of the national average. In the southern coastal and southwest regions, there is almost no heat consumption.

(5) Residential electricity consumption per capita: there is relatively less of a difference in terms of electricity power consumption. The consumption in the Beijing–Tianjin, southern, and eastern coastal regions is high, at 2.03 times, 1.54 times, and 1.53 times the national average, respectively. In the northeast and northern coastal regions, it is slightly higher than the national average. The consumption in the central, southwest, and northwest regions is below the national average, at 75, 74, and 63 % of the national average, respectively.

From the analysis above, we can see that the residents' needs for the five main energy sources in the various regions is not balanced; for example, the natural gas consumption per capita in the northeast region and the heat consumption per capita in the southern coastal and southwest regions are too low. Hence, it is particularly important to broaden the use of high-quality energy fuels, optimize the inter-regional energy transmission systems, and make reasonable adjustments and optimal allocations in the process.

4.4.2 Regional Comparison of the Structures of Residential Energy Consumption

There are significant differences in the energy structure of the various regions in China due to differences in energy resources, as well as the levels of economic development among the regions. In the following subsection, we will focus on the different proportions that each type of energy occupies in terms of consumption by region and the regional differences in the efficiency of energy use to compare the structures of energy use among regions.

4.4.2.1 The Residential Energy Consumption Structure by Region

Figure 4.17 shows that the energy consumption structure in various regions of the country is very different among the regions of China. In the central, southwest, and northern coastal regions, including the northeast and northwest regions, residential energy consumption is still coal-based, representing 54, 49, 42, and 40 % of the total consumption, respectively. In the southern coastal region, energy consumption is mainly oil and electricity, accounting for 55 and 33 % of the total, respectively. In the other regions, the energy consumption structure is relatively balanced (there is more heating consumption in the northeast region) and the proportion of oil consumption is relatively high in the eastern coastal, Beijing and Tianjin regions, accounting for 37, 46, and 30 % of the total energy consumption, respectively.

A comprehensive comparison of the residential energy consumption structure by region can be roughly divided into the following categories (Table 4.3):

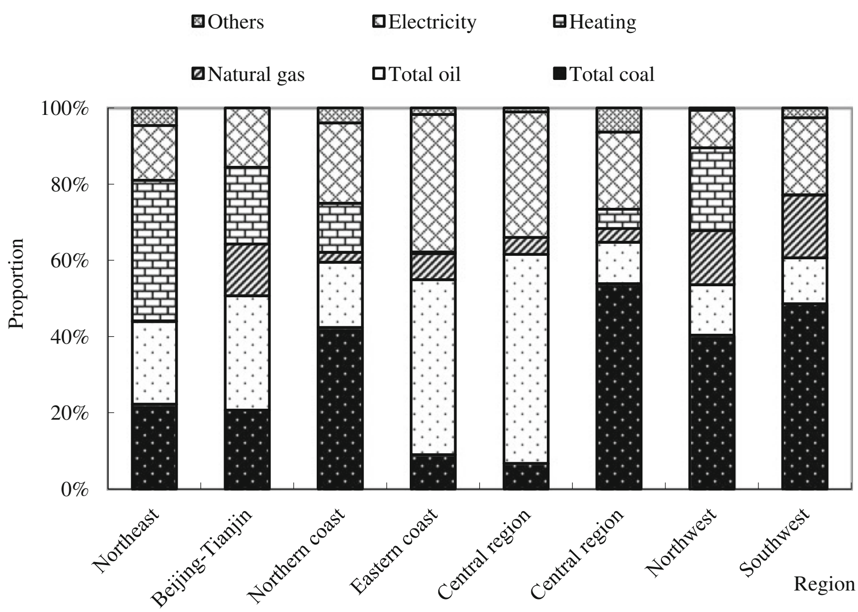

Fig. 4.17 Structure of residential energy consumption in eight regions (2007). *Data sources* NBS-DE, NBE-DCS (2009) and authors' calculations

Table 4.3 Structure of residential energy consumption by region

Energy structure	Region
Coal-based	Central, southwest, northern coastal, northwest
Oil-based	Southern coastal, eastern coastal
Both coal and oil	Northeast, Beijing–Tianjin
High efficiency	Northeast, Beijing–Tianjin, eastern coastal, southern coastal

(1) In the coal-based residential energy consumption structure, the proportion of coal is more than 40 %. The regions include the central region, the southwest region, the northern coastal region, and northwest region.
(2) In the petroleum-based structure, the oil ratio is greater than 40 %. The representative regions are the southern coastal and eastern coastal regions.
(3) In the coal- and oil-based structure, coal and oil consumption's share of the total domestic energy consumption is more than 20 %. The representative regions are the northeast region and Beijing–Tianjin Region.
(4) In the high-efficiency and high-quality energy consumption structure, the coal ratio is relatively small while the oil, natural gas, and electricity ratios are relatively high. The representative regions are the northeast region, Beijing–Tianjin region, eastern coastal region, and southern coastal region.

4.4.2.2 A Comparison of the Efficiency of Residential Energy by Region

Final demand utilization efficiency is the ratio of the final demand useful energy amount to the initial input energy amount. In accordance with the weighted average of the initial energy structure and the energy efficiency of different fuels, we can estimate the energy efficiency for a country or region (Hang 2007). In this subsection, we will evaluate the household sector's energy consumption structure using a weighted average of the different fuel efficiencies to estimate the utilization efficiency of final residential energy demand in each region. Specific data for energy utilization efficiency according to residential energy utilization efficiency, which is calculated by major terminal energy consumption types and terminal energy consumption equipment (Wang 2003), are shown in Table 4.4.

Table 4.4 Energy utilization efficiency in the residential sector

Energy	Coal	Oil	Natural gas	Electricity	Heat
Utilization efficiency/%	32	55	60	90	80

The oil utilization efficiency adopts the national average level in every sector

Table 4.5 Residential energy consumption structure and energy utilization efficiency by region

Region	Coal	Oil	Natural gas	Heat	Electricity	Efficiency (ranking)
Northeast	635.66	621.18	5.19	1056.51	411.33	42.00 (3)
Beijing–Tianjin	251.78	365.41	165.45	245.50	189.49	39.92 (4)
Northern coastal region	1140.77	460.73	69.87	346.26	567.01	36.41 (5)
Eastern coastal region	188.41	963.35	142.98	9.19	756.44	43.04 (1)
Southern coastal region	147.83	1206.30	97.76	–	724.94	42.46 (2)
Central region	2385.65	481.57	159.87	226.12	896.49	33.09 (8)
Northwest	1058.12	345.91	373.55	569.72	257.83	35.95 (6)
Southwest	1445.10	359.18	490.90	0.27	603.19	33.59 (7)

Unit 10^4 tce

Combining the types of energy in the regional energy consumption structure and the household sector's energy-use efficiencies shown in Table 4.4, we can calculate the final energy use efficiency for each region according to the above method and Eq. 4.1 (see Fig. 4.5).

$$P_i = \sum_{j=1}^{5} \alpha_{ij} p_j = \alpha_{i1} p_1 + \alpha_{i2} p_2 + \alpha_{i3} p_3 + \alpha_{i4} p_4 + \alpha_{i5} p_5 \tag{4.1}$$

P_i represents the regional household sector's final energy utilization efficiency for region i (i = 1–8);
α_{ij} is the ratio of region i, resource j to the total residential energy consumption (j = 1–5);
p_j is the energy utilization efficiency in the household sector for resource j (Table 4.5).

According to the above results, the energy utilization efficiency, as estimated by the residential energy consumption structure, varies by region. The energy utilization efficiency by region decreases according to the following order: eastern coastal region, southern coastal region, northeast region, Beijing–Tianjin region, northern coastal region, northwest region, southwest region, and central region. In general, the energy utilization efficiency of the eastern coastal and southern coastal regions is higher than the other regions because they are near a river and ocean and have convenient transportation networks. In light of current technical and economic developments, the energy utilization efficiency will improve in the other regions, but the potential varies by region. There is a gap among regions in which the efficiency of the central region differs by 10 % points from the eastern coastal region.

4.4.3 Impact Factors of Residential Energy Consumption: Examples from Three Regions

Energy is the important production factor of economic growth. Many domestic and foreign studies show that a country's economic growth and energy consumption have a significantly positive correlation (Kraft and Kraft 1978; Han et al. 2004). At the beginning of our analysis, we could not show that the GDP per capita and the residential energy consumption per capita had a very high correlation for the country as a whole and for each region. For example, the GDP per capita for the eastern coastal region is 1.8 times the national average, following the Beijing–Tianjin region, but its residential energy consumption per capita is below the national average. In addition, the residential energy consumption per capita for the northeast region is 1.6 times the national average, but its GDP per capita is the same as the national average. To find the reasons for the discrepancy between the residential energy consumption and economic development in the various regions, we have to consider the differences in the regional residential energy consumption patterns and explore the impact factors of residential energy consumption.

According to consumer demand theory and the non-renewable characteristics of fossil energy, the analysis shows that the main impact factors of per capita residential energy consumption include the urbanization process, technology level, per capita income, energy source prices, consumer preferences, regional differences, and energy availability. In the following subsections, we select the three regions (Beijing–Tianjin region, northeast region, and eastern coastal region) whose GDP per capita and residential energy consumption per capita are inconsistent as examples, to explore the influential factors affecting the levels of residential energy consumption.

4.4.3.1 Urbanization

In 2007, China's urban residential energy consumption per capita was 2.1 times that of rural households. Therefore, the process of urbanization process will make the residential energy consumption significantly increase. As more rural households become part of the urban population, this change will directly lead to a rapid increase in the demand for commercial energy sources and the residential energy consumption structure will become more optimal with each stage of development. In terms of the three regions, the regional urban population proportion is at its highest (81.18 %) in the Beijing–Tianjin region, which also has the highest amount of residential energy consumption per capita, while the northeast region is inferior in terms of urbanization (55.81 %) and has a relatively low amount of residential energy consumption per capita.

4.4.3.2 Technology Level

Improvement at the technical level and invention and application of new technologies and various equipments significantly improve energy efficiency. In particular, the household consumption of durable goods, such as refrigerators, air conditioners, is high; so the consumer demand for quality energy sources increases, which improves the energy utilization efficiency of final demand. Thanks to the development and utilization of natural-gas technology for heating and cooking, the households in megacities are gradually turning toward natural gas as a fuel source. This development shows that the demand for natural gas and other clean-energy sources cannot be suppressed, as verified from the Beijing–Tianjin region's residential consumption of natural gas.

4.4.3.3 Per Capita Income

According to economic theory, an increase in income will cause the normal commodity demand curve to move outwards. As household disposable incomes increase, the purchase of private cars and household appliances also increases. In the process, the households' energy consumption increases both in terms of quantity and quality. Residential energy use will become more diversified and will no longer be limited to meeting the needs of cooking, lighting, and heating. Energy use will also have a greater focus on improving the quality of life in terms of consumption of durable goods such as air conditioners, refrigerators, cars, and so on. The disposable income per capita for urban households in the Beijing–Tianjin region and the eastern coastal region is 1.7 times that in the northeastern region. From Table 4.6, we can see that in terms of the ownership of residential durable goods[4] in the three regions, Beijing and Shanghai are higher than Liaoning, especially in the number of cars (9.6 and 4.5 times that of Liaoning). The number of durable goods purchases increases in response to the increase in salaries and wages, which also leads to an increase in the demand for oil and electricity, which ultimately influences the residential energy consumption level.

Due to the difficulty in obtaining data, the ownership of residential durable goods was analyzed in some of the representative provinces that have the highest GDP per capita, including Beijing in the Beijing–Tianjin region, Liaoning in the northeast region, and Shanghai in the eastern coastal region.

Table 4.6 The ownership of residential durable goods in Beijing, Shanghai, and Liaoning (per 100 households) (2007)

Region	Private cars	Washing machines	Refrigerators	Color televisions	Private computers	Microwave ovens	Air conditioners
Beijing	19.85	102.24	108.13	146.99	91.62	87.84	157.29
Shanghai	9.37	97.85	103.51	183.41	103.90	96.10	190.93
Liaoning	2.07	91.31	95.27	121.74	44.43	50.02	16.99

4.4.3.4 Energy Prices

Higher energy prices will increase the family burden by reducing the family's purchasing power, which may encourage households to pay more attention to energy conservation or relatively inexpensive alternative fuels, changing the residential energy consumption level and consumption structure. For example, a family can use an air conditioner or electric radiator, which consumes electricity, but they can also use coal stoves and other equipment for heating, which consumes coal (all else equal in terms of comfort under moderate conditions). If the electricity price is relatively higher than the price of coal, then the residents will be biased toward using coal-based products for heating rather than electricity. The energy price is one of the main factors that affect the residential energy-consumption structure.

4.4.3.5 Residential Consumer Preferences

Energy consumption results in a number of environmental problems such as global warming, acid rain, dust, and so on. These environmental issues directly affect human health, and people have gradually come to realize that saving energy and protecting the environment are good for their health and well-being. The fact that people will pay more attention to reducing energy use in their daily lives and will prefer clean and "green" energy will contribute toward the sustainable development of energy and the environment. Two urban regions—the Beijing–Tianjin region and the eastern coastal region—have almost the same disposable income per capita of 19,841 yuan and 19,179 yuan, respectively. Accordingly, the main consumption of electrical appliances per one hundred households is roughly equal in Beijing and Shanghai. However, there is a considerable difference in private car ownership, as car ownership in Beijing is 2.12 times that of the Shanghai region, resulting in a very high level of fuel consumption per capita in Beijing. The different energy consumption levels also show that the public consumer preferences of the eastern coastal region are more energy-efficient and conscious of protecting the environment. To reduce energy consumption, people who travel should use more public transportation systems (in 2007, the Beijing–Tianjin region and the eastern coastal region were 18.0 and 11.6 units per 10,000 transport vehicles, respectively, while the total number of passengers using public transportation was 5.9 billion and 9.4 billion. This trend toward greater energy savings and environmental protection measures related to the public consumer preferences in the eastern coastal region has largely determined why the region's GDP per capita is high while its household energy consumption per capita is very low.

4.4.3.6 Geographical Differences

Regional distributions at different latitudes and under different climatic conditions mean that the regional residential energy consumption fuels and energy consumption quantities are significantly different. For example, China's central and northern residents are likely to require additional energy for heating in winter. During summer, the southern residents will have to consume a large amount of energy for refrigeration. Hence, geographical differences are an important factor that can affect the type and level of residential energy consumption.

4.4.3.7 Energy Availability

The differences in the regional energy supplies lead to differences in the availability of commercial energy at the regional level. For example, the Beijing–Tianjin region, northeast region, and eastern coastal region's supply of natural gas per capita is 201.57, 9.63, and 40.50 m^3, respectively, while their natural gas consumption per capita is consistent with the differences in supply. In terms of the consumption of natural gas per capita, the Beijing–Tianjin region leads, followed by the eastern coastal region and the northeast region. At the same time, the energy availability also has a great influence on the energy consumption structure of rural households. At the end of the 1990s, the rural power grid renovation project was launched, the availability of rural electricity was enhanced, and electricity prices fell, leading to a rapid increase in the consumption of electricity in the rural areas.

Because the factors cannot function independently, energy consumption is conditional on the combined influence of a number of factors. For example, the structure of energy consumption and consumer demand may sometimes be affected by income levels and energy prices. Only after living conditions have improved and revenues have increased, will people increase their demand to consume better quality energy. Under constant energy prices, people will always prefer the relatively inexpensive energy fuels. But when the energy prices decline, the quality of energy consumption has a tendency to rise and people are more conducive toward environmental protection and improving the quality of the new sources of energy.

In short, the analysis of residential energy consumption and its structure should be based on the actual situation of specific types of energy, along with comprehensive and in-depth research.

4.4.4 Characteristics of Regional Residential Energy Consumption

Unbalanced regional development is one of the basic national conditions of China, which is obvious in various social and economic fields, especially in residential energy consumption. The regional characteristics of residential energy consumption are mainly as follows:

(1) In all regions, residential energy consumption per capita can vary significantly. The highest consumption is in the Beijing–Tianjin region, which is up to 2.72 times the national average. The southwest region has the lowest consumption per capita, which is 76 % of the national average. In addition, the regional residential energy consumption per capita does not have a very high correlation with the regional GDP per capita. For example, the GDP per capita for the eastern coastal region is high (only lower than the Beijing–Tianjin region), but the region's residential energy consumption per capita is below the national average level.
(2) Subject to the constraints of the energy resource endowments, the optimal degree of the regional residential energy consumption structure also varies. The residential coal consumption of the southern coastal region is relatively low, so it has a relatively higher optimal level. The northwest region, southwest region, central region, and northern coastal region are still dominated by coal, but they need to be transformed toward a cleaner and higher quality energy structure.
(3) The regional differences in the residential energy structure determine the residential energy utilization efficiencies in the various regions. The energy utilization efficiencies, which are calculated by weighted means, show that the eastern coastal area has the highest residential energy efficiency at 43.04 % while the central region has the lowest at only 33.09 %, a difference of 10 % points.
(4) Through our analysis of residential energy consumption in three representative regions, the major factors that impact this demand include the process of urbanization, the technology level, per capita income, energy prices, regional differences, geographical differences, and energy availability.

4.5 Impact Analysis of Urban Residential Energy Consumption

In the previous subsection, we took the examples of the Beijing–Tianjin region, northeast region, and eastern coastal region to conduct a preliminary analysis of the factors influencing residential energy consumption. This subsection focuses on the historical and current situation of urban residential energy consumption and a quantitative analysis of the factors that impact the energy consumption of urban residents in China.

In recent years, China's urbanization rate rose from 17.9 % in 1978 to 46.6 % in 2009, and the average annual growth rate was 0.93 %. After 1995, the urbanization rate accelerated and the average annual growth increased by 1.26 % points. The urban growth rate has brought about a dramatic increase in the urban population, and the direct pursuit of a more comfortable life has led to a rapid growth in the energy consumption of urban households. The energy consumption structure has also undergone great changes. As shown in Fig. 4.11, the total energy consumption of China's urban residents has experienced a rising trend during the 1986–2007 period. In the last 10 years, the energy consumption of urban residents has grown very rapidly, with an average annual growth rate of 7.35 %. Total coal consumption has declined from more than 6000 tce per year to less than 2000 tce (calorific value calculations). The consumption volumes of oil, natural gas, heating and electricity have been increasing to varying degrees. Further research on the energy consumption of urban residents will help to guide more rational consumer behavior and promote energy savings in the household sector. It will also help to optimize the urban residential energy consumption structure and improve energy efficiency.

4.5.1 Impact Factors of Urban Residential Energy Consumption

Urban residential energy consumption can be affected by many factors, including the changes in the energy consumption structure, the residential income level and increases in purchasing power, living standards, and changes in consumer behavior, as well as changes in the use of various energy-consuming products and equipment. In addition, there are changes in social ownership and the promotion and application of new energy-saving technologies. Our analysis is based on previous studies and a combination of urban residential energy consumption characteristics. The main factors affecting the energy consumption of the household sector is attributed to the following six categories:

(1) Energy consumption structure differences. Different energy resource products have different energy input and output qualities, so the use of different accounting methods in different regions for different households may lead to different results respecting energy consumption.
(2) Population growth. Hirst et al. (1977) and Al-Ghandoor et al. (2009) pointed out the influence of the population on residential energy consumption. Whether there is a linear relationship between population growth and energy consumption and if yes, whether the elasticity is one, still need to be examined and discussed.
(3) Household income. Bentzen and Engsted (2001), Sardianou (2007), and Al-Ghandoor et al. (2009) have pointed out that there is a great influence of the households' income level on residential energy consumption. The improvement in living standards is bound to bring new popularity and greater consumption of energy-consuming products and equipment. For example, in 1985, there were 6.85 refrigerators and 48.29 television sets per 100 urban residents. By 2008, the two figures were 93.63 and 94.65 units, respectively. The improvement in living standards has also resulted in the expansion of the residential floor space per capita. In 1989, China's urban per capita housing area was 13.5 m^2, which doubled by 2006 to 27.1 m^2. This has, to a large

extent, led to a rise in residential lighting, heating, cooling, and energy consumption.

(4) Introduction of energy-saving equipment and the replacement of old equipment. Hirst et al. (1977) and Balaras et al. (2007) pointed out that technological progress as well as energy-saving technologies have a great impact on residential energy consumption. The promotion of energy efficiency in the household sector has resulted in the use of high-quality, energy-saving light bulbs instead of incandescent lighting, which not only reduces the power consumption but also improves the quality of lighting. In addition, relative to traditional fixed-speed air conditioners, there are obvious advantages in the energy efficiency of using air conditioner inverters to control and maintain set temperatures. Moreover, home insulation can save a lot of energy used for heating and cooling in the home.

(5) Lifestyle and people's attitude towards energy conservation. Wei et al. (2007) and Sardianou (2007) pointed out that people's attitude in terms of energy consumption and energy savings cannot be ignored. The energy consumption of the household sector includes continuity and interactions. Continuity refers to the fact that current energy consumption is impacted by past energy consumption, which means that people tend to maintain their existing lifestyles and essentially make the same decisions. The mutual influence and interests of neighbors and friends have a great influence too. Attitudes towards energy conservation and consumption are mainly divided into two aspects. The first is a type of lifestyle that is economical and respects conservation. For example, the purchase of energy-saving and environment-friendly cars that displace gas-guzzling luxury cars and living in apartments instead of luxury villas. The second is to reduce household energy waste by turning off the lights, setting reasonable air conditioning and heating temperatures, and disconnecting plugs to reduce standby power consumption. Energy consumption is different between standby and actual usage. The former belongs in the category of basic energy waste in which the average urban family uses the equivalent of 15–30 W of standby energy every day.

(6) The price of energy, tax subsidies, temperature, and other external factors. Sardianou (2007) and Al-Ghandoor et al. (2009) pointed out energy prices and tax subsidy policies have a great impact on the people's energy conservation attitudes and energy consumption. Zhang (2004) and Al-Ghandoor et al. (2009) focused on heating degree days, summer and winter temperatures, and other climactic factors, which impact residential energy consumption. In general, the higher the price of energy, the lower the total amount of energy consumption. Similarly, the higher the energy tax, the lower the total amount of energy consumption. Temperature also plays a role in the consumption of energy. Tropical areas basically have no winter season, so there is relatively no energy consumption related to heating but more energy consumption for refrigeration. In contrast, the northern boreal areas have basically no energy consumption related to cooling but much more energy consumption for heating.

4.5.2 Accounting Methodology and Data Description

(1) Energy consumption

To quantitatively analyze the influencing factors of energy consumption in the household sector, we must first account for total energy consumption and it is important to select the accounting method. The thermal equivalent method and Coal Consumption Act are two methods commonly used, but they do not consider differences in energy quality. Due to the many types of energy used by the household sector (such as cooking with propane or electricity and heating with coal or electricity), the differences in energy-quality impacts cannot be ignored. In considering the energy quality, we can study the residential sector energy consumption from a utility perspective. In other words, to meet our basic needs, how much useful energy should we consume? Jiang et al. (2006) presented the concept of the equivalent resistance method by using the second law of thermodynamics, which can be a good solution to the energy quality-difference problem.

All primary energies (coal, oil, natural gas, nuclear, solar, wind, hydro, etc.) can be used to generate electricity. If high-quality electricity is the standard and one transforms the final energy demand into electricity according to certain conversion coefficients, then one should not only consider the different types of energy in terms of "volume" but also in terms of "quality." Equivalent electrical conversion standard is as follows:

$$W = \eta \cdot Q \tag{4.2}$$

W is a form of energy or its numerical equivalent (kW h); Q is the type of energy in the form of total energy (kW h); and η is for the energy type's maximum conversion efficiency in which its value directly reflects the different energy grades and can be determined by the second law of thermodynamics.

The formula for calculating the equivalent electrical conversion efficiency for natural gas, oil, coal, and other products is as follows:

$$\eta_i = 1 - \frac{T_0}{T - T_0} \ln \frac{T}{T_0} \tag{4.3}$$

where i is natural gas, oil or coal; T_0 is the reference temperature (K); and T is the complete combustion temperature (K) for natural gas, oil, or coal.

The formula for calculating the electric conversion efficiency for hot water is as follows:

$$\eta\,(\text{hot water}) = 1 - \frac{T_0}{T_g} \ln \frac{T_g}{T_h} \tag{4.4}$$

where T_0 is the reference temperature in the targeted location (choose the local outdoor daily temperature in winter). T_g and T_h respectively represent the input and output temperatures of the water.

This subsection intends to use equivalent resistivity to calculate the provincial urban households' total energy consumption in China from 2003 to 2007 (Note: without any particular explanation, the residential section below refers to the Chinese provincial urban household sector). It then considers the corresponding timeframe and the regional impact factors of the total energy consumption, using the panel data of China's urban residential energy consumption for a multiple regression analysis. According to the above factors and the equivalent electrical energy characteristics, we construct our multivariate regression model according to the variables of population, disposable income per capita, summer and winter differences in temperature, energy prices, and whether or not there are collective heating systems. The various residential energy consumption quantities by province are derived from NBS-DITS and NDRC-BE (2004, 2005, 2006, 2007, 2008) and the reference temperatures are derived from NBS (2004, 2005, 2006, 2007, 2008).

(2) Population

Population is the main determinant of energy consumption and it is obvious that the changes in population have the impact on total energy consumption. The greater the population, the greater the need for more energy infrastructure and the greater the energy consumption. We can expect that the relationship between population and total energy consumption is always positive. In this section, the provincial population data are from NBS (2004, 2005, 2006, 2007, 2008). After 2005, the data are based on a sample survey of population change. The data in 2000 are from the Fifth Demographic National Census. Before 2005, the *China Statistical Yearbook* only gives the total population in each area and does not separate the urban and rural populations. Hence, we use the 2005 and 2000 urban population proportions for the moving average to obtain the 2001–2004 provincial urban population proportions, which are then multiplied by the total population to get the total population living in urban areas.

The population data in the *China Statistical Yearbook* are based on a sample survey, so these data can be used to determine the energy consumption by area.

(3) Disposable income per capita

Disposable income per capita largely reflects the residents' standard of living. An increase in living standards will result in an increase in household purchases of new products, resulting in the total energy consumption to rise; on the other hand, the replacement of products with low energy efficiency by more energy-saving appliances will greatly reduce the total energy consumption. Thus, it is difficult to determine the relationship between the disposable income of households and the consumption of energy. In the process of rising disposable income per capita, there are differences in spending patterns of energy-consumed equipment depending on the stages of development. For example, from 1985 to 1995, the number of refrigerators per 100 rural households increased from 6.58 to 66.22 while from 1995 to 2008, the number of air conditioners per 100 rural households increased from 8.09 to 100.30. The popular trends towards buying products that use high amounts of energy will cause total energy consumption to rise. When disposable incomes rise above a certain level, people are more likely to buy energy-saving products that replace older products to protect the environment, reduce emissions, or reduce the cost of energy over time. These responses result in a downward trend in terms of the total residential energy consumption. In addition, since the regional prices and resident purchasing powers are different, we use the purchasing power parity (PPP) method to calculate China's disposable income per capita from 2003 to 2007, which is a true reflection of the changing regional living standards over the years. As the statistical yearbooks only gave the consumer price indexes in different regions in the past, it is necessary to solve for the price differences by region. We use the PPP approach by Brandt and Holz (2006), who calculated the prices for the various regions in China in 2000, to make our own calculations from 2003 to 2007. The average disposable income per capita data was derived from NBS (2004, 2005, 2006, 2007, 2008).

(4) Temperature differences between summer and winter

Because the local latitudes and geographical conditions are different, the climate is very different, which has a great influence on the need for refrigeration in summer and heating in winter. However, the annual average temperature cannot be used to interpret the differences very well as places with great temperature differences during the year may have an average temperature equivalent to places where it is spring-like throughout. However, from the viewpoint of actual energy use, the demand for energy in an area with great temperature differences must be larger than that in an area whose climate is spring-like throughout the year. Therefore, we choose summer and winter average temperatures as explanatory variables in our regression analyses. As a result, it does not matter whether the area is tropical and there is a great need for cooling in summer and no need for heating in the winter, or whether the area lies in a frigid zone where there is a great need for heating in the winter and no need for cooling in the winter. Summer and winter temperature differences can be a very good indicator of the corresponding total energy consumption for a particular area—the greater the temperature difference, the greater the necessary energy consumption.

We select each provincial capital city's temperature as representative examples of their respective province. Apart from the fact that this data is easy to obtain, there are two other reasons for our selection: (1) the associated provinces have similar latitudes and geographical conditions, and the temperature differences are small and (2) the capital city is generally the largest city in the province, so it is given the largest weight in the calculations for the province as a whole. From the monthly temperature data, we find that July has the highest average temperature for most provinces and that January has the lowest. So, we use the July and January temperatures to calculate the temperature differences between summer and winter. The capital city temperature data are from NBS (2004, 2005, 2006, 2007, 2008).

(5) Energy price

Due to the different types of energy used in the residential sector, mutual substitution is common. Therefore, what the people choose in terms of the type of energy is often the most cost-effective; namely, they compare the cost of using different types of energy to produce the same result. When consuming energy, people always consider the cost-effective price of energy rather than its price per se. For example, when choosing between electricity and natural gas to heat water, they will consider the relative cost to boil the water. Hence, in the residential sector, the highest cost-effective price of the energy source has the greatest impact on total energy consumption.

Because the government has recently given financial subsidies on electricity, the prices of oil and gas are always relatively high (natural gas is not common). In the current stage, electricity has the highest cost performance. By using the Wind database, we can get the 2007 electricity prices in the different provinces. Then, according to the fuel price index from the "China Statistical Yearbook" and using the Brandt and Holz (2006) calculations in terms of PPP, we can calculate the provincial energy prices for the remaining years.

(6) Collective heating systems

In the northern part of China, there are collective heating systems, unlike in the south. Collective heating systems in most areas operate throughout the winter days and nights. When the indoor temperature is too high, people can only regulate the temperature by opening windows and doors, so the energy consumption is high. Many people in the southern regions only use the air conditioner to heat in times of need. In this respect, the people's response greatly reduces energy consumption. But the air conditioning heating efficiency is far lower than the efficiency of a collective heating system. With the improvement in living standards and the requirements to improve the quality of life, more people in the southern areas will choose air conditioning for heating in winter. So whether or not there are collective heating systems will impact the residential sector's energy consumption and this impact will change over time. Here, we need to make the following calculation in terms of collective heating (D). If there is collective heating, $D = 1$; if not, $D = 0$.

As stated above, the formula is:

$$\ln E_{it} = \beta_0 + \beta_1 P_{it} + \beta_2 I_{it} + \beta_3 W_{it} + \beta_4 EP_{it} + \beta_5 EP_{i,t-1} + \beta_6 D_{it} \tag{4.5}$$

where E_{it} indicates province i in year t (the residential energy consumption calculated by the electrical equivalent method); P_{it} indicates the urban population of province i in year t; I_{it} indicates the disposable income per capita discounted at PPP for province i in year t; and W_{it} represents the average temperature difference between summer and winter for province i in year t. EP_{it} represents the energy prices in province i in year t and D_{it} represents collective heating systems in province i in year t.

4.5.3 Results Analysis and Discussion

We create a mixed model (model I, model II) and an individual random effects model (model III, model IV), respectively, using the pooled least squares method and the pooled EGLS method to obtain the model parameter values as follows (Note: Figures in brackets are the t-test) (Table 4.7).

As can be seen from the t-test in Model I, $\ln(EP_t)$ and $\ln(EP_{t-1})$ have an obvious collinearity. The coefficient of $\ln(EP_{t-1})$ is larger than $\ln(EP_t)$ and it is more significant. Hence, we remove $\ln(EP_t)$ and build Model II. As can be seen from the results of the two models, energy price is significant to energy consumption in the urban residential sector and lagged time is more influential than present time, which coincides with the conclusion of Bentzen and Engsted (2001). All parameters passed the test in Model II.

Table 4.7 A regression analysis of the urban household energy consumption factors in China

	Model I	Model II	Model III	Model IV
C	7.703***	7.478***	6.047***	6.453***
	(3.71)	(4.02)	(3.17)	(3.88)
$Ln(P)$	0.776***	0.774***	0.679***	0.683***
	(16.26)	(16.40)	(7.23)	(7.40)
$Ln(I)$	0.856***	0.870***	1.255***	1.239***
	(5.48)	(5.96)	(6.34)	(6.34)
W	0.022**	0.021**	0.029***	0.030***
	(3.25)	(3.26)	(3.58)	(3.85)
$Ln(EP_t)$	−0.255		0.271	
	(−0.25)		(0.46)	
$Ln(EP_{t-1})$	−0.686	−0.927***	−1.367**	−1.134***
	(−0.69)	(−4.25)	(−2.33)	(−3.51)
D	0.205**	0.205**	−0.192*	−0.186
	(2.20)	(2.20)	(−1.68)	(−1.63)
R^2	0.759	0.759	0.489	0.492

*Indicates a significant level of 10 %, **indicates a significant level of 5 %, and ***indicates a significant level of 1 %

According to the t-test in Model III, $\ln(EP_t)$ is a redundant variable which shares colinearity with other variables, Therefore, we remove this variable and build another model. The results are shown in Model IV. Except for D, the remaining variable coefficients are at the 1 % significance level. The coefficient of the variable D is also close to the 10 % significance level and as this coefficient value is large, it will be retained.

When establishing an individual effects model, one needs to conduct a Hausman test to determine whether one should use an individual fixed effects model or an individual random effects model. An individual fixed effects model cannot occur when the variables change with time, so by removing the D variable and then reexamining the results, we find a value of 0.23, where the 1, 5, 10 % of the significance levels are not refused by the null hypothesis, which means that the individual effects and regression variables are unrelated. Therefore, creating a model of the individual effects should be conducted by establishing an individual random effects regression model.

Since the establishment of a mixed model and an individual random effects model is quite different, we need to determine which model is more reasonable. Hypothesis testing:

H_0 The same intercept of the model for different individual variables (the real model for a mixed regression model)

H_1 The intercept differences of the model for different individual variables (real model for an individual random effects regression model)

The statistic F is defined as:

$$F = \frac{(SSE_r - SSE_u) \,/\, [(NY - k_1 - 1) - (NT - N - k_2)]}{SSE_u \,/\, (NT - N - k_2)} \tag{4.6}$$

where SSE_r represents the residual sum of squares of the hybrid estimation model and SSE_u represents the residual sum of squares of the individual random effects model.

After the calculation, $F = 10.32 > F_{0.95}(29, 115) = 1.56$, to reject the null hypothesis, we can establish our individual random effects regression model.

The sample data is across time periods, so the disposable income per capita of the household sector energy consumption may change over time, so we should also carry out further inspections. The coefficient before the $\ln(I)$ annually over time for a change, Wald test, p-value of the F-test, and Chi-square test are both 0.79; therefore, the impact of income on energy consumption does not change over time.

In summary, in terms of the total energy consumption of the household sector, the disposable income elasticity is 1.24; that is, in the case where other conditions remain unchanged, when the disposable income per capita increases by 1 %, the total energy consumption of the household sector rises by 1.24 %. The increase in the number of urban residents in China from 2003 to 2007 has resulted in a tendency to spend more household income on energy consumption relative to maintaining the original consumption structure. In the long term, it is difficult for the 1.24 elasticity coefficient to remain unchanged. With further improvement in incomes and in the upgrading of the consumption structure, the elasticity coefficient may rise further. When the consumption structure upgrades to a certain level, the energy consumption of the entire residential structure will include more low-end consumer products and the elasticity coefficient will begin to decline.

The elasticity of the total energy consumption of the household sector is 0.68; that is, when there is an increase of 1 % in the population, the total energy consumption of the household sector rises by 0.68 %. First, this value is positive and in line with our sense of economics: that is, the greater the population, the greater the total energy consumption of the household sector. Second, the value is less than 1, indicating that the population representing the total energy consumption of the household sector is not on the same sliding scale. This can be called the broad scale effect; that is, the population growth plays a role in reducing the per capita energy consumption in the household sector.

In terms of the total energy consumption of the household sector for the last year of our data set, the actual energy price elasticity was −1.13; that is, when energy prices rose by 1 %, the total energy consumption of the household sector decreased by 1.13 %. First, the value is negative, which is in line with economic theory—the higher the energy prices, the lower the total energy consumption in the residential sector. Second, the elasticity of the absolute value is greater than 1, indicating that the energy consumption of urban residents in China is very sensitive to energy prices. Because of long-term financial subsidies for the Chinese people, the actual price of the regional energy fuels has not changed much in the past five years, so energy consumer prices have remained stable. Therefore, the residents' annual expenditures for energy have also been relatively stable. But when energy prices rise, the residents will very easily feel the increase on their spending budgets and they will use a variety of ways to reduce energy consumption in the subsequent years. In addition, due to the characteristics of the household sector, the energy consumption patterns have rigidity. If energy prices continue to rise, then the absolute degree of flexibility between fuels may be reduced to a very small extent. Even when there is a shortage of energy and energy prices are high, there is the option of accessing stored energy at a time when the energy price elasticity is likely to be positive.

In addition, in terms of the summer and winter variables, the temperature differences and whether or not there are collective heating systems also have a great impact, with coefficients of 0.03 and −0.19, respectively. For every increase in the temperature difference of 1 °C between summer and winter, the household sector's total energy consumption will rise by 3 %. In the case in which the other conditions remain unchanged and a region has collective heating systems, the total energy consumption in the household sector will be reduced by 19 % compared with the case in which there are no collective heating systems. This shows that at this stage, the air conditioning for hearing has become popular for the southern urban residents. The impact of increasing the extent of collective heating system in areas which are cold in winter but without collective heating system will decrease the total energy consumption and the decrease extent is large according to the last period. Turning off the collective heating systems when they are not needed will greatly enhance the energy-saving rate.

4.5.4 Conclusions

This section uses the panel data of the 2003–2007 energy consumption of urban residents in the provinces in China to analyze the influencing factors of the population, disposable income per capita, temperature differences between summer and winter, energy prices, and whether or not there are collective heating systems. Other influencing factors, such as technological progress, government policies and measures, resident lifestyles, energy-saving attitudes, and missing data are difficult to quantify and they have affected the accuracy of the results. Of all the influencing factors included within the scope of this study, population and energy prices are the two main factors that can be controlled to mitigate the effects of greater energy consumption. Through our research, we believe that the following:

(1) in terms of population, we should continue to adhere to the basic national policy of family planning. If China's population in 2020 reaches 1.5 billion and the urbanization rate is 55 %, then the energy consumption of the household sector will be 4.7 % greater than that under a controlled population of 1.4 billion.
(2) in terms of energy prices, it is appropriate to raise energy prices and then subsidize low-income families, which will effectively reduce total energy consumption. A 10 % increase in energy prices combined with a 10 % income subsidy (in terms of disposable income per capita) to the lowest 20 % of the population will reduce the total energy consumption of the household sector by approximately 10 %.

4.6 Summary

Residential energy consumption has become an important part of China's final energy consumption and a current energy analysis of energy policy research is important. This chapter begins with residential energy consumption from a national perspective using representative examples. It systematically analyzes the energy consumption of the overall characteristics of the household sector in China, compares the energy consumption characteristics of urban and rural households and regional areas, and quantitatively analyzes the main factors of the energy consumption of urban residents, drawing the following main conclusions:

(1) Whether in developed or developing countries, the household sector accounts for a large proportion of final energy consumption. Moreover, in the developed countries, the living standards are significantly higher than those in the developing countries. Furthermore, the energy consumption patterns of the household sector are not the same in different countries at the same level of development. Therefore, a reasonable guide to the energy consumption behavior of the household sector is to study the progress of development in

terms of "savings" that are conducive to the energy savings of the household sector. With the improvement in living standards, the countries' structure of energy consumption is developing in a high-quality, low-carbon direction, but the household sector energy consumption coefficient of carbon emissions in China, India, and other developing countries is also very high, so the optimization of many countries' energy structures still has much room for improvement.

(2) The household sector is the second-largest sector in terms of energy consumption in China. In the process of building a moderately prosperous society, the standard of living in the country is speeding up, the absolute amount of residential energy consumption is gradually increasing, and the energy consumption per capita has continued to increase. Since the reform and opening-up period, China's residential energy demand structure has significantly improved. The proportion of coal to final energy consumption continues to fall and the energy consumption structure of final demand includes more high-quality and cleaner fuels. Limited to natural energy resources, China needs to further optimize its energy consumption structure by increasing the conversion rate from coal to electricity. The proportion of electricity consumption in terms of final energy demand has become very important.

(3) Affected by the long-standing dual economic structure of China, the level of residential energy consumption between urban and rural areas is significantly different. The energy consumption per capita of urban residents is 2.1 times that of rural residents. With the improvement in living standards, the expansion of urban housing, and the rapid growth of private car ownership, the gap between the urban and rural household energy consumption levels has been widening. There are also large differences between the urban and rural areas in terms of the types of energy consumption. Urban residents have changed from mainly coal consumption patterns to high-quality natural gas, oil, electricity, and other clean energies, while rural areas are still dominated by coal. Therefore, how to meet the effective demand of urban residents, reasonably guide consumer behavior, control the excessive growth of energy consumption and optimize the energy consumption structure of rural life, and reduce the proportion of the direct combustion of coal are the current problems that should be solved.

(4) Due to the inter-regional allocation of resources, the level of economic development, economic structure, as well as the level of household consumption, there are considerable regional differences in energy consumption, consumption structures, and energy use efficiencies. In general, residential energy consumption per capita in the Beijing–Tianjin region is the highest, followed by the northeast region. According to the energy consumption structure, the energy utilization efficiency of the eastern coastal region and southern coastal region is higher because of their convenient transportation networks and coastal geography. But in the central region and the southwestern region, the efficiency is 35 % or less than the national average. The energy efficiency gap among regions endows China with great potentials in

energy-saving field under its current level of economic and technical development. Therefore, based on the differences in energy-use characteristics of the current level of economic development, it is important to study the various regions to improve their energy efficiency potential and possibilities.

(5) The elasticity between the urban sector's energy consumption and disposable income per capita is 1.24; that is, in the case in which all other conditions remain unchanged, when the disposable income per capita increases by 1 %, the total energy consumption of the urban sector will increase by 1.24 %. The elasticity of the urban residential energy consumption to the total population is 0.68; that is, an increase of 1 % in the population means that the total energy consumption of the urban residential sector will increase by 0.68 %, and the population representing the total energy consumption of the household sector is not on the same sliding scale. In a broad sense, population growth plays a role in reducing the energy consumption per capita in the household sector. The energy price elasticity for the urban sector's energy consumption in the last year of our study period was −1.13. The absolute value of the elasticity is greater than 1, indicating that the energy consumption of urban residents in China is very sensitive to energy prices. In addition, the temperature difference between summer and winter and the collective heating system coefficients for the urban sector were 0.03 and −0.19, respectively. When there is an increase in the summer and winter temperature difference of 1 °C, the urban sector's total energy consumption will increase by 3 %. If all other conditions remain unchanged and a region has collective heating systems, the total energy consumption of the urban sector will decline by 19 % compared with a region without collective heating systems.

References

Al-Ghandoor A, Jaber JO, Al-Hinti I et al (2009) Residential past and future energy consumption: potential savings and environmental impact. Renew Sustain Energy Rev 13(6–7):1262–1274

Balaras CA, Gaglia AG, Georgopoulou E et al (2007) European residential buildings and empirical assessment of the Hellenic building stock, energy consumption, emissions and potential energy Savings. Build Environ 42(3):1298–1314

Bentzen J, Engsted T (2001) A revival of the autoregressive distributed lag model in estimating energy demand relationships. Energy 26(1):45–55

Brandt L, Holz CA (2006) Spatial price differences in China: estimates and implications. Econ Dev Cult Change 55(1):43–86

Department of Energy of National Bureau of Statistics, Department of Comprehensive Statistics of National Energy Administration (2008) China energy statistical yearbook 2007. China Statistics Press, Beijing

Department of Energy of National Bureau of Statistics, Department of Comprehensive Statistics of National Energy Administration (2009) China energy statistical yearbook 2008. China Statistics Press, Beijing

Department of Industry and Transport Statistics of National Bureau of Statistics, Bureau of Energy of National Development and Reform Commission (2003) China energy statistical yearbook 2000–2002. China Statistics Press, Beijing
Department of Industry and Transport Statistics of National Bureau of Statistics, Bureau of Energy of National Development and Reform Commission (2004) China energy statistical yearbook 2003. China Statistics Press, Beijing
Department of Industry and Transport Statistics of National Bureau of Statistics (1990) China energy statistical yearbook 1989. China Statistics Press, Beijing
Department of Industry and Transport Statistics of National Bureau of Statistics (1998) China energy statistical yearbook 1991–1996. China Statistics Press, Beijing
Department of Industry and Transport Statistics of National Bureau of Statistics (2001) China energy statistical yearbook 1997–1999. China Statistics Press, Beijing
Department of Industry and Transport Statistics of National Bureau of Statistics, Bureau of Energy of National Development and Reform Commission (2005) China energy statistical yearbook 2004. China Statistics Press, Beijing
Department of Industry and Transport Statistics of National Bureau of Statistics, Bureau of Energy of National Development and Reform Commission (2006) China energy statistical yearbook 2005. China Statistics Press, Beijing
Department of Industry and Transport Statistics of National Bureau of Statistics, Bureau of Energy of National Development and Reform Commission (2007) China energy statistical yearbook 2006. China Statistics Press, Beijing
Department of Industry and Transport Statistics of National Bureau of Statistics, Bureau of Energy of National Development and Reform Commission (2008) China energy statistical yearbook 2007. China Statistics Press, Beijing
Department of Industry and Transport Statistics of National Bureau of Statistics, Bureau of Energy of National Development and Reform Commission (2009) China energy statistical yearbook 2008. China Statistics Press, Beijing
Han ZY, Wei Y-M, Jiao J-L et al (2004) On the cointegration and causality between Chinese GDP and energy consumption. Systems Engineering 22(12):17–21
Hang LM (2007) Research on energy structure in China. Shanghai Jiaotong University, Shanghai
Hirst E, Lin W, Cope J (1977) A residential energy use model sensitive to demographic, economic, and technological factors. Q Rev Econ Financ 17(2):7–22
IEA (2009) CO_2 emissions from fuel combustion: highlights, 2009th edn. International Energy Agency (IEA), Paris
Jiang Y, Liu LB, Yang X (2006) Discussion on the calculation method of different energy type in energy statistics. Energy of China 6(6):5–8
Kraft J, Kraft A (1978) On the relationship between energy and GNP. J Energy Dev 3(2):401–403
National Bureau of Statistics (2004) China statistical yearbook 2004. China Statistics Press, Beijing
National Bureau of Statistics (2005) China statistical yearbook 2005. China Statistics Press, Beijing
National Bureau of Statistics (2006) China statistical yearbook 2006. China Statistics Press, Beijing
National Bureau of Statistics (2007) China statistical yearbook 2007. China Statistics Press, Beijing
National Bureau of Statistics (2008) China statistical yearbook 2008. China Statistics Press, Beijing
Sardianou E (2007) Estimating energy conservation patterns of Greek households. Energy Policy 35(7):3778–3791
State Information Center (2005) Inter-regional input-output production table. Social Sciences Academic Press, Beijing
Wang QY (2003) China's energy efficiency and international comparison. Energy Conserv Environ Prot 8:8–14

Wei Y-M, Fan Y, Han ZY et al (2006) China energy report (2006): strategy and policy research. Science Press, Beijing

Wei Y-M, Liu L-C, Fan Y et al (2007) The impact of lifestyle on energy use and CO_2 emission: an empirical analysis of China's residents. Energy Policy 35(1):247–257

Wei Y-M, Liu L-C, Fan Y et al (2008) China energy report (2008): carbon emissions research. Science Press, Beijing

World Bank (2009) World development indicators 2009. World Bank, Washington DC

Zhang Q (2004) Residential energy consumption in China and its comparison with Japan, Canada, and USA. Energy Build 36(12):1217–1225

Chapter 5
Energy Efficiency in Key Sectors

China is in the process of rapid industrialization and urbanization, with faster growth in energy consumption related to transportation, construction, electric power, and other sectors. Private transport is developing quickly and the quantity of petroleum used by the transportation sector continues to account for a large proportion (about three-quarters) of total consumption. With the rapid development of the tertiary industry and the continuous improvement in the people's living standards, energy consumption in the construction industry will also remain at a high level. According to the experience of the developed countries, the percentage of energy consumption used for buildings may grow continually. China is also the second-largest electricity producing country and the proportion of electric power in meeting final energy demand is rising each year. The efficiency of coal power generation and that of transmission and distribution directly affects the energy efficiency of the power generation sector. Focusing on the study of the energy efficiency problems of the transportation, construction, and electric power industries has great significance towards energy savings and emission reductions for society as a whole. Therefore, this chapter focuses on the following issues:

- What are the main characteristics of energy use in the transportation sector?
- What are the factors that influence the energy intensity of the transportation sector?
- What features do the developed countries have in terms of energy consumption in the transportation sector? What inspirational programs or lessons can we learn?
- What are the features of public construction projects in terms of energy consumption?
- What is the efficiency of electricity generation as well as transmission and distribution?

Y.-M. Wei and H. Liao, *Energy Economics: Energy Efficiency in China*,
DOI 10.1007/978-3-319-44631-8_5

5.1 Transportation Sector

Transportation is a significant foundation and service industry for the national economy and for social development. Meanwhile, it is also a key sector of national energy consumption, especially petroleum. With the rapid development of the national economy, improvement of people's living standards, and acceleration of urbanization, the transportation industry is becoming one of the main sectors of energy consumption and growing greenhouse gas (GHG) emissions. Today, approximately 30 % of the global energy consumption and 25 % of the global CO_2 emissions come from transportation. It is estimated that the energy consumption of global transportation will double by 2050. Further, transportation-related CO_2 emissions must be slashed (IEA 2009; Wang 2008). Improving energy efficiency of the transportation sector has great practical significance in terms of accelerating the transformation of transportation networks, promoting the development of a "green" and low-carbon economy, and building a resource-saving and environment-friendly society. We are going to systematically study several important issues, such as the characteristics of China's transportation sector in terms of energy consumption, factors influencing the amount of transportation energy consumption, a comparison between China and foreign countries in terms of transportation energy consumption, and related energy savings and emission reduction policies and measures.

5.1.1 Energy Consumption Characteristics in China's Transportation Sector

5.1.1.1 A Study of Total Energy Consumption in Transportation and Its Structural Evolution

As the *China Statistical Yearbook*, *China Energy Statistical Yearbook,* and other authoritative statistical data sources only show the gross energy consumption amounts for such categories as transportation and postal and warehousing industries, we cannot further subdivide the transportation sector into subcategories such as road, waterways, urban, rail, air, and other modes of transport. At the same time, the energy consumption amounts and percentages of the handling, warehousing, and postal industries are quite small (approximately 7.6 % in 2007, according to the NBS data). Thus, we adopt the energy consumption amount of the transportation, warehousing, and postal industries as the approximate value for the transportation industry as a whole. Figures 5.1 and 5.2 show the results based on NBS-DITS (1990, 1998, 2001), NBS-DITS and NDRC-BE (2003), NBS-DE and NBE-DCS (2009), and our calculations. It is worth noting that because of the persistent problems in the construction and organization of the administrative system (and other factors), China's transportation industry statistics only include commercial transportation. Non-commercial transportation vehicles, such as private cars,

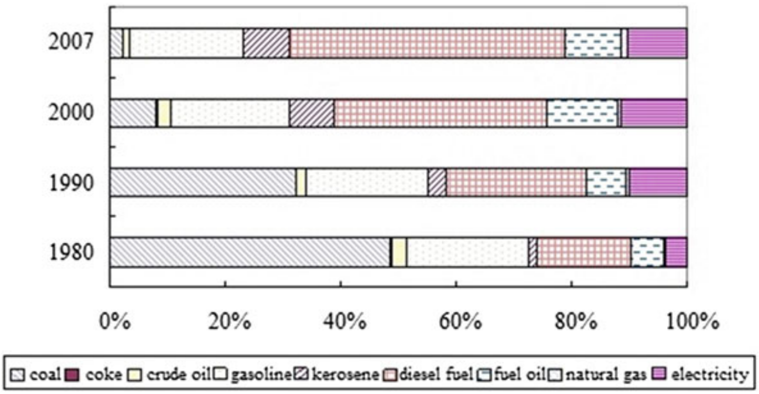

Fig. 5.1 Comparison of the structure of transportation energy consumption in China (1980–2007). *Data sources* NBS-DITS (1990, 1998, 2001), NBS-DITS, NDRC-BE (2003), NBS-DE, NBE-DCS (2009) and authors' calculations

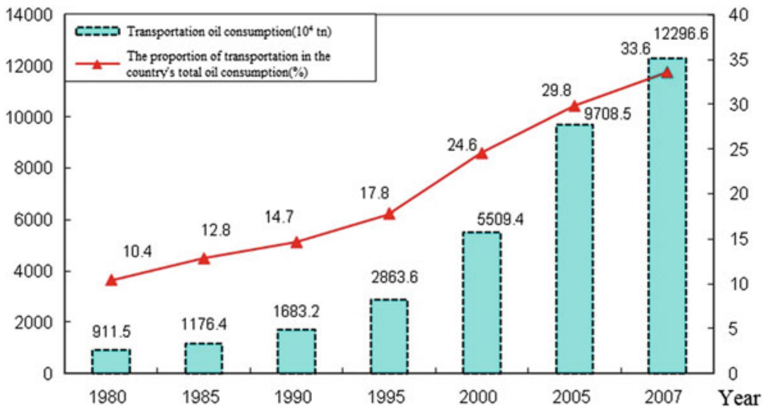

Fig. 5.2 Transportation oil consumption and its proportion of the total (1980–2007). *Data sources* NBS-DITS (1990, 1998, 2001), NBS-DITS, NDRC-BE (2003), NBS-DE, NBE-DCS (2009) and authors' calculations

yachts, and motorbikes, are not included, which is different from international statistical standards. Moreover, refueling abroad is widely practiced in international shipping and air transport.

In recent years, the total energy consumption of the transportation sector in China has grown rapidly and the sector's structure has improved continuously. It is mainly characterized by the following basic features:

(1) From the perspective of the energy consumption structure, petroleum products take up the largest proportion of energy consumption in the transportation sector.

The energy consumption in the transportation sector includes petroleum, electricity, natural gas, coal, and other kinds of energy in which petroleum products take priority. From 1980 to 2007, the structure of energy consumption in the transportation industry has changed dramatically—from coal and oil products to petroleum products (see Fig. 5.1). In 2007, the proportion of oil consumption in the transportation industry was 86.2 % of the total energy consumption, an increase of 39.3, 29.0, and 6.5 %, respectively, compared with that of 1980 (46.9 %), 1990 (57.2 %), and 2000 (79.8 %).

(2) From the perspective of overall trends of the total amount of energy consumption, the energy consumed by transportation—especially road transport—has grown rapidly.

The transportation sector is one of the main energy-consuming sectors, especially for petroleum. From 1980 to 2007, the average annual growth rate of total energy consumption in the transportation sector was 7.54 %. However, in the same period, the national average annual growth rate of energy consumption was 5.65 %, in which oil consumption grew by leaps and bounds—increasing by 12.5 times from 9.115 million tons in 1980 to 122.966 million tons in 2007—an average annual growth rate of 10.12 %. This rate was 0.86 times higher than that of the national petroleum consumption, becoming the main driver in the growth of petroleum consumption. At the same time, the proportion of transportation petroleum consumption increased from 10.4 % in 1980 to 33.6 % in 2007, an increase of 23.2 %, making it the second-largest petroleum consumer after the industrial sector.

From 2000 to 2005, the growth of total energy consumption by various modes of transport (pipeline energy consumption is very small and negligible) is shown in Fig. 5.3. The data is according to CCYP (2001, 2002, 2003, 2004, 2005, 2006), MOT-CATS (2009a), MOR (1990, 1998, 2001), CCAC-DPT (2003), and our

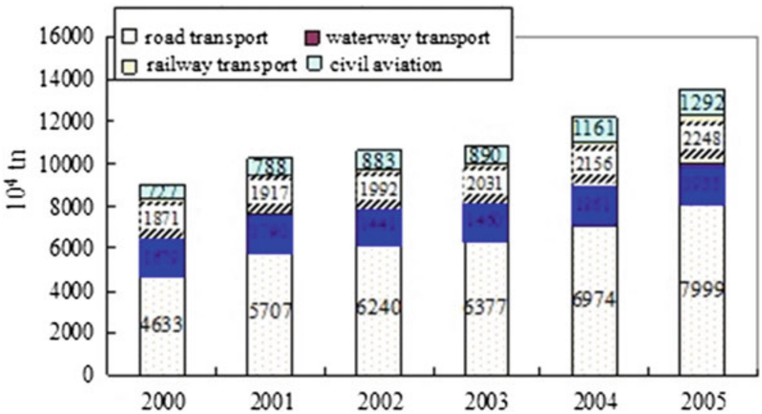

Fig. 5.3 Total energy consumption growth by various modes of transport (2000–2005). *Data source* CCYP (2001, 2002, 2003, 2004, 2005, 2006), MOT-CATS (2009a), MOR (1990, 1998, 2001), CCAC-DPT (2003) and authors' calculations

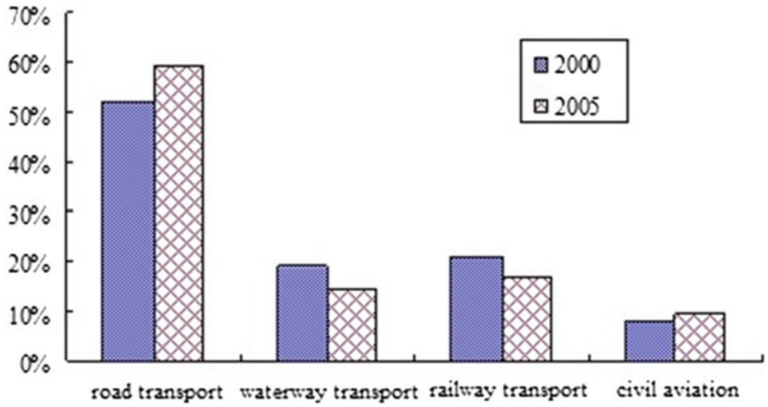

Fig. 5.4 The proportion of energy consumption by various modes of transport (2000 and 2005). *Data sources* CCYP (2009), MOT-CATS (2009a), CCAC-DPT (2003) and authors' calculations

calculations. Through our analysis, we find that energy consumption in civil aviation and road transport has grown particularly fast, with an average annual growth rate of 12.2 and 11.5 %, respectively. The energy consumption by railways and waterways has increased slightly, at an annual rate of 3.7 and 2.9 %, respectively. Thus, the imbalance in the growth of energy consumption among various transportation modes has led to a significant change in the proportions of the energy consumption composition. The proportions by various modes of transport in China in 2000 and 2005 are shown in Fig. 5.4. The data is according to CCYP (2009), MOT-CATS (2009a), CCAC-DPT (2003), and our calculations. It can be seen from the figure that the greatest amount of energy consumption is for road transport, followed by railways and waterways. Civil aviation consumes the smallest amount of energy. The total energy consumption of road transport in 2000 accounted for about 52.0 % of the total transportation sector, and it increased to 59.4 % in 2005.

(3) From the perspective of energy intensity, the overall energy consumption of transportation per unit after conversion has declined. However, the value added of the energy consumption per unit has risen.

There are two major types of energy intensity indicators. One is the product consumption per unit (e.g., per ton of steel, comprehensive converted turnover of railway, and so on) and the other is the energy consumption per unit of output (e.g., GDP, added value of industrial production, income of principal place of business, and so on). Corresponding to the national mandatory targets (energy consumption per unit of GDP) and according to the characteristics of the transportation industry (the service industry, in which displacement service for passengers and freight is the main product), as well as considering the continuity of the industry statistics, we consider energy consumption per unit after conversion and energy consumption per unit of value added (Fig. 5.5).

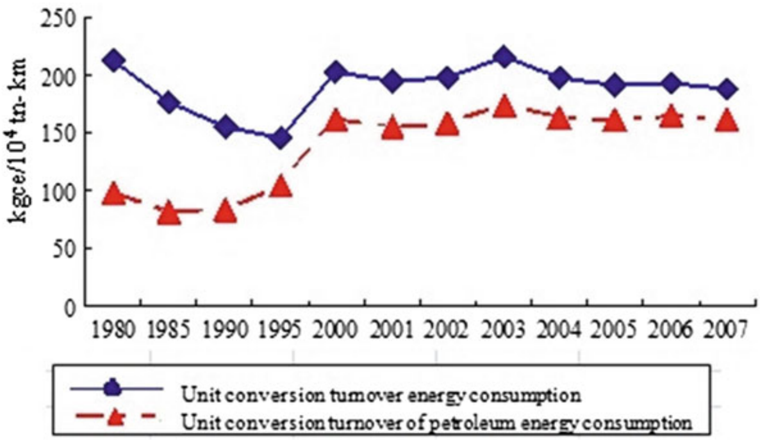

Fig. 5.5 The energy consumption per unit after conversion in China's transportation industry (1980–2007). *Data sources* NBS (2010) and authors' calculations

From the energy consumption per unit after conversion in the transportation sector, we find three different phases in terms of the characteristics of changes in the transportation sector during the 1980–2007 period. However, the overall tendency is downward. Due to technology improvements, especially the acceleration in railway locomotive electrification, the total energy consumption declined from 213.15 kgce per ten thousand tons in 1980 to 146.08 kgce in 1995. Because of the acceleration in road infrastructure construction and the rapid increase in highway mileage from 1995 to 2000, the number of motor vehicles grew and the overall energy consumption per ten thousand tons rose to 202.6 kgce in 2000. The energy consumption has fluctuated since 2000, but the overall trend is downward, falling to 187.55 kgce per ten thousand tons in 2007 (an average annual decline rate of 1.10 %).

From the energy consumption of per unit of value added, we can see that the transportation sector also shows three similar stages, especially the upward trend since 2000. In 2007, the energy consumption per ten thousand yuan added in the transportation sector was 1.78 tce (see Table 5.1). The data comes from NBS (2010) and our calculations. Compared with 1980 and 2000, there was an increase

Table 5.1 Situation of China's transportation industry energy consumption per unit of added value (1980–2007)

Year	1980	1985	1990	1995	2000	2001	2002	2003	2004	2005	2006	2007
Energy consumption per unit value added (tce/10^4Yuan)	1.24	1.31	0.92	0.70	1.04	1.04	1.10	1.27	1.46	1.54	1.65	1.77

The added value of transportation is at constant 2005 prices of 42.47 and 71.00 %, respectively, or an annual rate of 1.32 and 7.97 %, respectively. This indicates that the transportation sector should make great efforts to reverse the current development trend to contribute to the national objective of decreasing energy consumption per unit of GDP by 20 % during the Eleventh Five-Year Plan.

5.1.1.2 The Changing Trends of Energy Intensity in Transportation

(1) Highway transportation

As mentioned above, based on the current statistics of China's transportation sector, road transportation energy consumption only contains the energy consumption of commercial vehicles; private cars are not included in the official industry statistics. Thus, the main analytical scope of this study is the commercial road transportation. The main road transport energy intensity indicators are as follows:

(a) The composite energy intensity of gasoline and diesel

From 2000 to 2005, there is was an overall increase in the energy consumption (gasoline and diesel) per unit of commercial vehicles. The energy intensity of operating the vehicles was 8.84 kgce per 100 ton-kilometers (tn-km) in 2005, an increase of 21.8 % compared with 7.46 kgce in 2000, or an annual increase of 3.44 % (as shown in Table 5.2). The data comes from CCYP (2000a, 2001, 2002, 2003, 2004, 2005, 2006) and our calculations.

(b) Classified fuel consumption per 100 ton-kilometers

Dividing the number of passenger and freight transport vehicles by fuel type, the change in the amount of the classified commercial vehicles' fuel consumption per 100 tn-km from 1980 to 2007 is shown in Table 5.3. The data are from CCYP (2000a, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008). From 2000 to 2007, the fuel consumption per 100 tn-km of classified commercial vehicles had a steady and increasing trend. Energy consumption per unit of passenger cars increased year-on-year while the trucks' energy consumption per unit was stable. In 2007, the energy intensity of gasoline- and diesel-fueled passenger cars was 13.1 and 12.2 L per 100 tn-km, respectively. In addition, gasoline and diesel trucks consumed 8.3 and 6.3 L per 100 tn-km, respectively. It is clear that when operating passenger cars or trucks, diesel fuel consumption per 100 tn-km is lower than gasoline fuel consumption overall, thanks to the high thermal content of diesel fuel and energy efficiency of diesel engines.

(2) Water transportation

Water transportation is divided into inland waterways and maritime transportation (including coastal and ocean shipping). Commercial transportation is the main source of energy consumption and the main fuel types are fuel oil and heavy diesel oil. In recent years, the energy intensity of commercial ships has shown a downward

Table 5.2 China's commercial vehicle energy consumption (2000–2005)

Year	2000	2001	2002	2003	2004	2005	Average annual growth (%)
Commercial vehicle (10^4 tce)	4632.9	5706.9	6240.0	6377.1	6973.9	7998.9	11.54
Commercial bus (10^4 tce)	1056.9	1648.2	1512.8	1980.1	1452.9	1721.4	10.25
Commercial truck (10^4 tce)	3575.9	4058.6	4727.1	4396.9	5520.9	6277.5	11.91
Total gasoline and diesel (10^4 tn)	3163.5	3899.7	4266.8	4363.2	4770.6	5472.9	11.59
Gasoline (10^4 tn)	1633.4	1720.1	1597.3	1366.3	1583.9	1700.7	0.81
Diesel (10^4 tn)	1530.0	2179.6	2669.5	2996.9	3186.7	3772.2	19.78
Commercial vehicle (kgce/100 converted tn-kn)	7.46	8.79	8.87	8.68	8.00	8.84	3.44
Commercial bus (kgce/1000 persons-km)	17.98	25.61	21.61	28.73	16.61	20.94	3.09
Commercial truck (kgce/100 tn-km)	6.36	6.94	7.46	6.61	7.04	7.63	3.70

1. Calculations based on total energy consumption and turnover of commercial highway passenger and cargo
2. Transportation converted turnover of commercial highway (converted ton-kilometers) = freight turnover of commercial highway + passenger turnover of commercial highway/10

trend. The statistics show that compared with 2000, fuel consumption per 1000 tn-km decreased by 39.4 % on average in 2005; an average annual decline of 6.86 %. During the period of the “Tenth Five-Year Plan” the fuel-energy consumption per unit of commercial ships decreased from 8.70 kgce per 1000 tn-km in 2001 to 7.77 kgce per 1000 tn-kms in 2005, a decrease of 10.7 %. The fuel energy consumption per unit of marine ships decreased 11.4 % while that of inland ships was relatively flat, with a small decline of 2.0 % (Table 5.4). The data comes from CCYP (2000a, 2001, 2002, 2003, 2004, 2005, 2006). Today, China's energy efficiency technology for its ocean vessels is close to international standards but that for its coastal and inland vessels still has a big gap compared with the developed countries. In particular, the fuel consumption of inland ships is still 10–20 % higher than that of foreign vessels in the advanced countries (Office of the National Energy Leading Group 2006; National Development and Reform Commission 2004). In response to the shipping energy savings programs during the “Tenth Five-Year Plan,” China's energy consumption per shipping unit dropped significantly and energy savings were a remarkable achievement, although there is still room for significant improvement overall (Table 5.5).

Table 5.3 Energy consumption per 100 ton-kilometers for different types of commercial vehicles in China (1980–2007)

Year	1980	1985	1990	1995	2000	2001	2002	2003	2004	2005	2006	2007
kgce/100 tn-km												
Gasoline bus	8.17	8.71	9.47	9.91	11.98	13.07	10.89	13.07	13.07	14.37	13.94	14.26
Diesel bus	7.22	7.47	8.81	10.53	11.02	9.79	12.24	13.46	13.46	14.20	13.71	14.93
Gasoline truck	9.47	8.38	7.73	6.86	7.62	8.71	8.71	8.71	8.71	8.71	8.60	9.04
Diesel truck	7.59	6.49	5.88	5.39	6.12	7.34	7.34	7.34	7.34	7.71	7.96	7.71
litre/100 tn-km												
Gasoline bus	7.5	8.0	8.7	9.1	11	12	10	12	12	13.2	12.8	13.1
Diesel bus	5.9	6.1	7.2	8.6	9	8	10	11	11	11.6	11.2	12.2
Gasoline truck	8.7	7.7	7.1	6.3	7	8	8	8	8	8	7.9	8.3
Diesel truck.	6.2	5.3	4.8	4.4	5	6	6	6	6	6.3	6.5	6.3

Table 5.4 The commercial ships' total fuel consumption and per unit energy consumption (2000–2005)

Year	2000	2001	2002	2003	2004	2005	Average annual change rate (%)
Total fuel consumption (10^4 tce)	1679.0	1790.0	1440.9	1459.7	1861.1	1937.7	2.9
Fuel consumption per 1000 tn-km (kgce/ktn-km)	13.14	10.57	8.57	9.00	8.14	9.43	−6.4
Total fuel consumption (10^4 tn)	1175.3	1253.0	1008.6	1021.8	1302.8	1356.4	2.9
Fuel consumption per 1000 tn-km (kg/ktn-km)	9.2	7.4	6.0	6.3	5.7	6.6	−6.4

Table 5.5 The commercial ships' energy consumption by location (2001–2005)

Year	2001	2002	2003	2004	2005	Average annual change rate (%)
Commercial ship	8.7	8.59	7.96	7.73	7.77	−2.79
Inland ship	11.57	11.33	11.49	11.6	11.34	−0.50
Marine ship	8.49	8.39	7.69	7.44	7.51	−3.02

Unit kgce per kiloton km

(3) Railway transportation

Since the 1980s, China's steam locomotives were gradually replaced by diesel and electric locomotives. By 2003, the steam locomotives were completely eliminated as a form of railway transportation, and rail power was achieved through internal combustion engines and electrification. By continuously adjusting and optimizing the locomotive structure, the total energy consumption of railway transportation in terms of workload per unit decreased from 180.5 kgce per 104 ton-km in 1990 to 88.6 kgce per 104 ton-km in 2005, an average annual decline of 4.6 % (Table 5.1). The data comes from NDRC-CTRI (2007). The "Eleventh Five-Year Plan" by the Ministry of Railways indicates that it is necessary to promote the application of a variety of advanced and comprehensive resource-utilization technologies related to oil savings and oil substitutes, electricity savings, water savings, new energy sources, renewable energy, and so on. These measures will actively promote cleaner energy production and improve railway energy use and resource efficiency. However, as the core railway-development strategy has been speeding up in recent years, it is getting increasingly difficult to save energy while improving travel comfort and convenience (Table 5.6).

Table 5.6 National energy consumption of the railway transportation sector (1990–2005)

Year	Total energy consumption	Transportation workload	Energy consumption of per unit transportation workload	Main transportation energy consumption of per unit transportation workload	Locomotive energy consumption of per unit transportation workload
	10^4 tce	10^8 converted tn-km	kgce/10^4 converted tn-km		
1990	2385.1	13,211.3	180.5	160.5	122.9
1995	2399.3	16,378.6	146.5	–	–
2000	1870.6	17,858.7	104.8	84.2	–
2001	1916.9	19,005.4	98.6	–	62.1
2002	1992.2	20,022.2	100.1	82.4	–
2003	2030.7	21,098.4	96.3	77.7	60.4
2004	2156.0	23,797.4	90.6	77.5	59.4
2005	2247.5	25,366.6	88.6	76.3	57.8
Average annual growth rate (%)					
1990–2005	−0.4 %	4.4 %	−4.6 %	−4.8 %	−4.9 %
2000–2005	3.7 %	7.3 %	−3.3 %	−2.0 %	–

The per unit energy consumption of the national railway's diesel, electric, and steam locomotives from 1990 to 2008 is shown in Fig. 5.6. The data comes from MOR-SC (2008, 2009a, b), CCYP (2000b), NBS (1987, 2005, 2007a, b, 2008, 2009), and our calculations.

From the energy consumption per unit of various types of locomotives, the electric locomotives are the most energy efficient, followed by the diesel locomotives; steam locomotives are the most inefficient. In recent years, China's railway

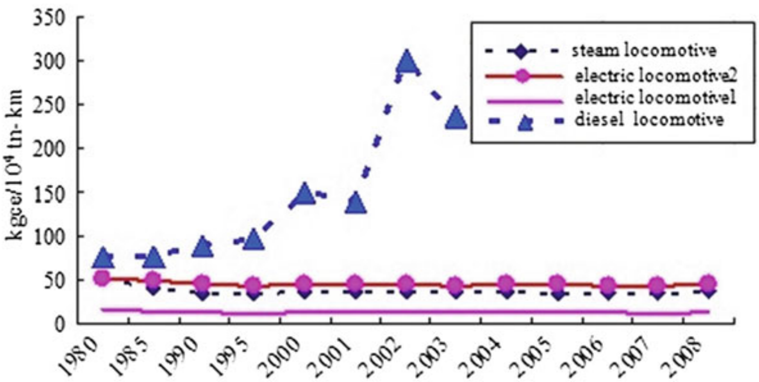

Fig. 5.6 Per unit energy consumption of diesel, electric and steam locomotives (1990–2008). The electric locomotives 1 and electric locomotives 2 were calculated using calorific values and coal equivalents, respectively

transportation equipment structure has been further optimized. By 2003, most steam locomotives had been taken out of service and there has been a gradual increase in the efforts towards the electrification of the railway networks. The proportion of diesel locomotives is also declining.

(4) Air transportation

The civil aviation transportation subsector is an important part of our integrated transportation system, but it is also the main energy consumption subdivision and greenhouse gas emitter. Since the reform and opening-up period, the sustained and rapid development of China's civil aviation transportation industry has resulted in a rapidly expanding fleet and substantial increases in related fuel consumption every year. The total energy consumption growth in the national civil aviation industry from 1980 to 2007 is shown in Table 5.7. In 2007, China's civil aviation fuel consumption was 11.3 million tons, an increase of 32.25 times and 2.29 times that in 1980 and 2000, respectively, with average annual growth rates of 12.5 % and 13.9 %. In recent years, as fuel prices continually rose, the estimated average annual growth rate of the cost of aviation fuel is over 20 %, so that the profit margin of airline companies is further squeezed. According to IATA's estimate of emissions, every ton of aviation kerosene consumption will produce 3187 kg of $CO_{2,}$ 1239 kg of water, 0.98 kg of $SO_{2,}$ 0.56 kg of CO, and 21.12 kg of NO_X. Although the carbon emissions of air transportation are less than 2 % of the total global carbon emissions, most of the emissions are directly exhausted into the stratosphere because of the cruising altitude of most airplanes, thus exacerbating global warming. Therefore, the reduction of emissions by the aviation transportation industry is gaining greater international attention. To this end, China's civil aviation industry is making a great effort towards energy conservation by controlling its fuel consumption to reduce costs and greenhouse gas emissions. Moreover, the industry recognizes the importance of sustainable development by improving its air service capacity and quality while achieving a rapid decline in unit energy consumption. From 1980 to 2007, the unit consumption per ten thousand tn-kg by the national civil aviation industry decreased quickly from 11,624 to 4547 kgce (see Table 5.7), an average annual decline of 3.4 %. The data comes from CCYP (2000b) and CAAC-DPD (2008, 2009).

(5) Per unit energy consumption of different transportation modes

Different technical and economic characteristics of highways, waterways, railways, airports, and other transportation modes result in great differences in per unit energy consumption. From our comparison of per unit energy consumption for the various modes of transportation in 2005 (see Table 5.8, The data comes from CCYP (2009), MOT-CATS (2009a), NBS-DITS (1990, 1998, 2001), CCAC-DPT (2003), NDRC-CTRI (2007) and our calculated), we find that the railways and waterways are the two lowest, at 88.6 and 83 kgce per 10^4 tn-kilometers, respectively. The highway transportation per unit energy consumption is 868.4 kgce per 10^4 ton-km. However, air transportation has the highest energy consumption, at 4944 kgce per

Table 5.7 National civil aviation's total energy consumption and energy intensity (1980–2007)

Index	1980	1985	1990	1995	2000	2001	2002	2003	2004	2005	2006	2007	Average annual change rate (%)
Total energy consumption (10^4 tce)	50.00	97.10	174.57	399.38	727.06	788.04	882.96	890.02	1160.60	1292.01	1472.19	1662.52	13.9
Per unit energy consumption (kgce/10^4 tn-kg)	11,624	7651	7357	6371	5900	5591	5356	5209	5017	4944	4856	4547	−3.4
Total oil consumption (10^4 ton kerosene)	33.98	65.99	118.64	271.43	494.13	535.57	600.08	604.88	788.77	878.08	1000.54	1129.89	13.9
Per unit oil consumption (kg kerosene/tn-kg)	0.79	0.52	0.50	0.433	0.401	0.38	0.364	0.354	0.341	0.336	0.33	0.309	−3.4

Table 5.8 Per unit energy consumption of the transportation modes (2000–2005)

Year		2000	2001	2002	2003	2004	2005
Highway	Commercial vehicle	527.0	703.4	746.4	878.9	886.6	868.4
	Commercial bus	1592.3	1629.5	1798.0	2560.8	2161.1	2873.2
	Commercial trucker	411.4	606.5	636.3	693.8	745.8	660.8
Waterway	Transportation ship	131.4	105.7	85.7	90	81.4	94.3
	Commercial ship	–	87.0	85.9	79.6	77.3	77.7
	Marine ship	–	84.9	83.9	76.9	74.4	75.1
	Inland ship	–	115.7	113.3	114.9	116	113.4
Railway	Energy consumption of per unit transportation workload	104.8	98.6	100.1	96.3	90.6	88.6
	Main transportation energy consumption of per unit transportation workload	84.2	–	82.4	77.7	77.5	76.3
	Locomotive energy consumption of per unit transportation workload	–	62.1	–	60.4	59.4	57.8
	National railway diesel locomotive	25.8	25.7	25.9	25.4	25.0	24.6
	National railway electric locomotive	113.2	113.1	110.8	110.0	111.2	111.8
	National railway steam locomotive	207.8	195.0	421.3	330.5	–	–
Aviation	Per unit energy consumption of civil aviation	5900	5591	5356	5209	5017	4944

Unit kgce per 10,000 ton-kilometers

10^4 tn-km. According to total energy consumption per unit after conversion, water transportation is the lowest among the four modes, whereas railway, highway, and air transportation are approximately 1.1 times, 10.4 times, and 59.5 times that of water transportation, respectively.

5.1.2 Systematic Analysis of the Impact of Energy Intensity on Transportation

Transportation energy savings are a complex system of engineering features that affect many factors. In general, these factors can be grouped into three categories: structural factors, technical factors, and management factors (MOT-DCP 2008, 2009).

5.1.2.1 Systematic Analysis Framework of Energy Intensity Impacts on Transportation

With alternative transportation services provided by the various modes of transportation, making full use of the comparative advantages of these modes and building comprehensive integrated transportation systems for the country and society as a whole are the most important methods of energy savings. Therefore, we should first strive to improve the integrated transportation system and consider the overall energy consumption of the transportation sector. We can solve for the energy consumption of the transportation unit, also known as the energy intensity of transportation, by using the following formula:

$$\frac{E}{V} = \sum_i \left(\frac{V_i}{V} \times \frac{E_i}{V_i}\right) = \sum_i \left[\frac{V_i}{V} \times \left(\sum_j \frac{V_{ij}}{V_i} \times \frac{E_{ij}}{V_{ij}}\right)\right] \tag{5.1}$$

Among the variables, V is the total transportation turnover of passengers (goods); V_i is the transportation turnover mode (for highways, waterways, railways, airlines, and pipelines); and V_{ij} is the internal transportation turnover of a certain mode of transportation. This formulation can have different classifications, such as the transportation turnover of gasoline and diesel vehicles in the composition of road transportation and the sharing in the amount of transportation turnover in different types of highways; the proportional shares of turnover of diesel locomotives and electrified locomotives in railway transportation; or the proportional shares and substitution of passengers among small- and medium-sized passenger cars, buses, railways, airlines, and so on. E_{ij} is the amount of energy consumed by mode of transportation and activity.

On the right side of the formula, V_i/V is the proportion of a particular mode of transportation in an integrated transportation system. V_{ij}/V_i is the structure of a certain mode of transportation within a subsector (such as the proportion of commercial and non-commercial vehicles in road transportation, or the proportion of river, coastal, and ocean carriers [boats and ships] in terms of waterway transportation). E_{ij}/V_{ij} is the energy consumption per unit by subsector for each transportation mode (such as the per unit energy consumption of gasoline cars or trucks and diesel buses or trucks in the commercial road transportation subsector). Thus, this formula can be decomposed as follows:

$$\begin{aligned}
&\text{Transportation's comprehensive energy intensity}\\
&\quad = \text{structure of comprehensive transportation}\\
&\qquad * \text{per unit energy intensity of each transportation mode}\\
&\quad = \text{structure of comprehensive transportation}\\
&\qquad * \text{inner structure of each transportation mode}\\
&\qquad * \text{per unit energy intensity by mode of transportation and type of equipment}
\end{aligned} \tag{5.2}$$

Thus, the change in transportation energy intensity can be decomposed into three parts and it can take into account all of the transportation sectors and subsectors within society as a whole. It shows that all modes of transportation (V_i), each internal structure of the various modes of transportation (V_{ij}/V_i), and the per unit energy consumption of each subsector within each transportation mode (E_{ij}/V_{ij}) will impact a country's total transportation energy intensity.

With this formula, we can see that there are three main ways to reduce the energy intensity of transportation:

(1) Adjust and optimize the structure of an integrated transportation system by increasing the proportion of the transportation modes with low-energy intensities. For example, vigorously develop waterways and railways, giving full play to their comparative advantages of large transportation capacity and low energy consumption, giving priority to the development of public transportation, and so on. This represents structural energy savings at the macro level of an integrated transportation system.
(2) Optimize the internal structure of various modes of transportation by developing energy-efficient transportation infrastructure, including the equipment and enterprise structures, with low energy consumption and high efficiencies, such as improving the road network, promoting large-scale transport, specialization and standardization, and promoting the electrification of railway locomotives. These options represent the internal structural energy consumption within each transport sector.
(3) Promote the transportation advances in technology and use technical measures to improve the efficiencies of transportation vehicles, loading and unloading machinery, and other key energy consumption equipment. Further, reduce the energy intensity of activities within the various transportation subsectors, such as energy consumption per 100 passenger-kilometers for commercial vehicles and per tn-km for freight transport and so on. These options represent technical energy savings within the various modes of transportation.

5.1.2.2 Analysis of the Impact Factors of Transportation Energy Consumption

(1) Analysis of the relationship between the transportation structure and energy consumption

The structural factors that influence transportation energy conservation include two levels: the integrated transportation structure and the inner structure of various modes of transportation (Zhang 2006). The integrated transportation structure is an important factor in transportation energy consumption. For a long time, China's highways, waterways, railways, airports, pipelines, and other modes of transportation have belonged to different authorities. Moreover, the convergence and coordination among them is poor, affecting the comparative advantages of various modes of transportation and the full benefits of combined efficiencies. Therefore, the overall energy efficiency is relatively low. At present, with China's further system reforms and the formation of the Ministry of Transport (MOT), the construction of an integrated transportation system provides a good opportunity for the development of integrated transport networks. Besides, the structure of integrated transport networks is becoming more reasonable in terms of cost and the potential for energy savings, which must have far-reaching impacts in the transportation sector.

The internal structure of the various modes of transportation includes the transport infrastructure, transportation equipment, organizational structure of transportation enterprises, and energy consumption structure. Taking road transportation as an example, we can see that its structure includes the design and layout of roads, transportation hubs, cars and tractor-trailers, the proportions of heavy, medium and light trucks, the proportion of intensive, large-scale road transportation enterprises and the proportion of gasoline, diesel and renewable energy vehicles.

(2) Analysis of relationship between transportation technologies and energy consumption

Technical factors that influence transportation energy savings include the technical performance of the manufactured transportation equipment, state of the transportation equipment and technical operations, energy-saving technologies (products), advanced energy technologies, application of information technology, and so on. Among the factors, the road transportation energy-saving technical factors include the vehicle manufacturers' technical performances, their status in terms of vehicle technology, the vehicles' energy-saving technologies (products), information technology applications, and so on (Cai et al. 2006). In addition, water transportation's energy-saving technical factors include ship design and manufacturing technology, status of marine technology, marine energy-saving products, shipping information on the levels of the technical state, and auxiliary facilities.

(3) Analysis of the relationship between transportation management and energy consumption

The managerial factors influencing transportation energy conservation include the level of transportation efficiency, traffic management, standards of eco-driving, operations of transportation organization and management levels, transportation energy-saving regulations and standards, incentive policies, institutional mechanisms, and so on.

Energy conservation management is also known as the energy savings of a system. Relative to technical energy savings and structural energy savings, it is indirect and integrated. On the one hand, improving the effects of energy conservation management will eventually be attributed to structural optimization and technological progress. In addition, technical energy conservation and structural energy conservation also can be achieved by strengthening the management structure. The common management tools include improving the technology policies, strengthening the scientific and technological innovations, and constructing results-based promotional systems. In addition, other tools include strengthening strategic planning guidance in terms of the constraints of existing regulations and standards and policy and system incentives; the comprehensive use of economic, legal, administrative, education, and other means to optimize the transportation modes by encouraging the public to travel "green"; strengthening the management of transportation organizations; reducing the rate of driving alone and increasing the rate of carpooling; improving the transportation efficiency and so on.

5.1.3 International Comparison of Energy Consumption in Transportation

The study collected a large number of first-hand material officially released by the transportation sectors of developed countries and regions, such as US, Japan, European Union (EU), and others. Through a comprehensive and systematic comparison between China and other foreign countries and an analysis of the energy consumption of domestic and international transportation by typical modes, we looked for similarities and differences to provide references for the choices of potential energy-saving practices by transportation modes in China.

5.1.3.1 Transportation Energy Consumption Characteristics of Typical Countries and Regions

(1) From the viewpoint of total energy consumption, the transportation sector's energy consumption for the society as a whole is engaged in utilizing a higher proportion of energy and it is in an upward trend.

As a key energy-consuming sector, transportation energy consumption accounts for a higher proportion of society's total energy use. According to the statistics of typical countries and regions, the proportion of their transportation sector's energy consumption is between 15 and 30 %.

In US and Japan, transportation is the second-largest energy consuming sector and its energy consumption proportion is rising. According to the statistics of the U. S. Department of Transportation (DOT), the U.S. energy consumption proportion for transportation remained between 25 and 29 % of the total from 1975 to 2008, which is the second-largest energy consumption sector after industry. The total energy consumption of the transportation sector is less than that of the total industrial sector but higher than that of the residential and commercial sectors, with an increasing trend (Fig. 5.7). The energy consumption of the transportation sector relative to that of the industrial sector in the US is much higher than that in China as the proportion of industry in the US is lower than it is in China. This situation is related to the fact that the US has transferred a great amount of heavy industry, which has high energy consumption, to developing countries.

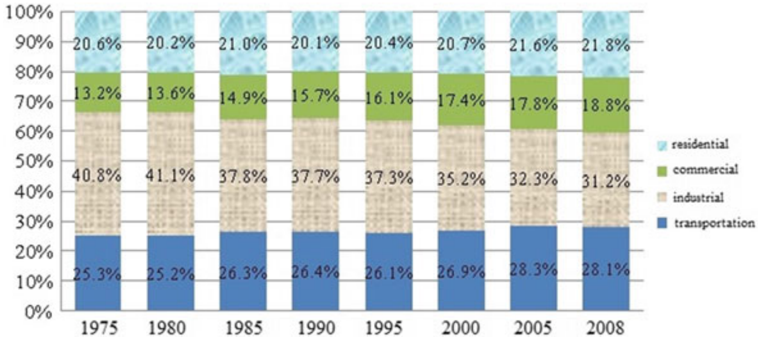

Fig. 5.7 The proportion of energy consumption by sector in the US, 1975–2008. *Data source* ORNL (2009)

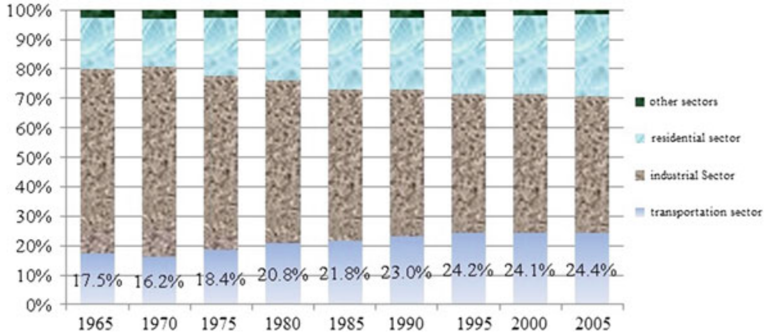

Fig. 5.8 The proportional change in energy consumption by sector in Japan (1965–2005). *Data sources* IEEJ (2007) and authors' calculations

According to the IEEJ (2007) and our calculations, the transportation sector's energy consumption from 1965 to 2005 is shown in Fig. 5.8. The proportion of transportation's energy consumption to the total for Japan is between 16.2 and 24.4 %, making it the second-largest energy consumption sector after the industrial sector. The total energy consumption of the transportation sector is less than that of the industrial sector but higher than that of the residential sector and other sectors, and it shows an increasing trend that has tended to stabilize in recent years.

The proportion of transportation energy consumption continues to rise in the EU and it represents close to one-third of the total energy consumption. According to the EU-25 energy statistics (see Table 5.9). The proportion of the transportation industry's energy consumption to the total has increased every year, from 26.8 % in 1990 to 30.8 % in 2004.

Overall, from the point of view of the total energy consumption for society as a whole, the transportation industry now accounts for the largest proportion, so it is an important sector in which to influence the energy efficiency of the region.

Table 5.9 The structure of energy consumption, including the transportation sector, in the EU-25 (1990–2004)

Year	Transportation	Proportion in total energy (%)	Industry	Other sectors	Total energy consumption
1990	389	26.8	476	584	1449
1995	421	28.8	436	610	1466
2000	477	30.7	446	630	1553
2001	481	30.3	447	663	1590
2002	486	30.9	443	644	1573
2003	493	30.5	450	671	1614
2004	503	30.8	456	674	1631
Change rate (%)	29.3	14.9	−4.2	15.4	12.6
Average annual change rate (%)	1.9	1.0	−0.3	1.0	0.8

Unit million tce

(2) From the viewpoint of energy structure, the proportion of road transportation energy consumption is relatively high in the transportation industry.

Based on the internal energy structure of the transportation sector, road transport energy consumption accounts for a high proportion because it includes a variety of transportation modes.

Road transportation energy consumption accounts for more than two-thirds of the total transportation energy consumption in the US. The transportation energy consumption structure of the US has a comprehensive network: civil aviation is the main mode that is committed to long-distance passenger transportation; railways are mainly responsible for part of the goods and passenger transportations; waterways and pipelines account for relatively lower amounts of energy while the remainder of the passenger traffic and freight transport is related to the road transport subsector. The most important area of transportation energy consumption is highway traffic, which accounts for more than two-thirds of the total energy consumption in the transportation sector. In contrast, the energy consumption by railways is small, at only 2.40 % of the total (as shown in Fig. 5.9). Without considering the urban rail transportation system, the energy consumption of the U.S. railway system, which has the same caliber as that in China, is only approximately 2 % of the total energy consumption. Because of the different transportation structure in the US, the proportion of road transport is highest, followed by civil aviation; but the unit energy consumption level of the road traffic is much larger than the other modes of transportation. Moreover, because of the expansive landscape, low petroleum prices, lifestyle, and other factors, the transportation system in the US is the highest energy-consuming sector from the perspective of energy efficiency.

Road transportation energy consumption in Japan accounts for more than 80 % of the transportation sector. The proportional changes in the structural energy consumption of the various modes of transportation in Japan from 1965 to 2005 are

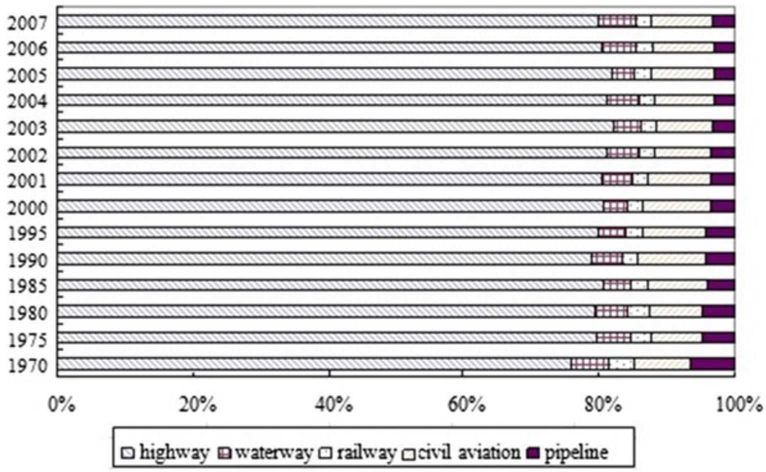

Fig. 5.9 Transportation energy structure in the US (1970–2007). *Data source* ORNL (2009)

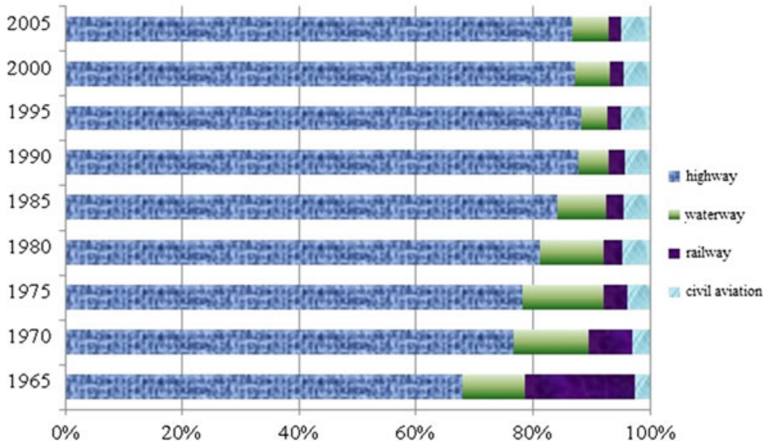

Fig. 5.10 Structural changes of the proportion of energy consumption of the various transportation modes in Japan (1965–2005). *Data source* IEEJ (2007). *Note* The road passenger transport, including private passenger cars, sales of passenger cars and buses

shown in Fig. 5.10. In the past 40 years, Japan has basically constructed an integrated transportation system whose main energy consumption is from buses, trucks, and automobiles. Today, road transportation energy consumption accounts for more than 87 % of the total transportation energy consumption.

According to Eurostat (2009) and our calculations (as shown in Table 5.10), it is clear that the road transportation energy consumption in the EU accounts for more than 80 % of the total transportation energy consumption, which itself accounts for

Table 5.10 The proportion of transportation energy consumption in the EU-25 region (2004 and 2006)

Subject	2004		2006	
	Energy consumption (Mtoe)	Proportion	Energy consumption (Mtoe)	Proportion
EU25	1140.9	–	1141.4	–
Industry	318.9	27.9 %	311.0	27.2 %
Residential, service, and etc.	471.1	47.3 %	476.3	40.9 %
Transport	350.3	30.8 %	363.2	31.8 %
Highway	289.7	82.7 %	296.8	81.7 %
Railway	8.6	2.5 %	9.0	2.5 %
Aviation	47.0	13.4 %	51.1	14.2 %
Inland navigation	5.0	1.4 %	5.9	1.6 %

30 % of the total energy consumption within the EU. In terms of the transportation sector, road transportation is energy-intensive. As for the EU-15, the road transportation energy consumption takes up 82.4 % of the total energy consumption in the transportation sector. In contrast, that for railways is extremely low, at only 2.4 % of the total transportation energy consumption and 0.8 % of the total energy consumption in the region.

As for the EU-25 region, the total energy consumption of the transportation sector accounted for 30.8 % in 2004. Among the various modes of transport, the road transportation's fuel consumption accounted for 81.7 % in 2006 while that for the total transportation sector represented 31.8 % of the region's total energy consumption. In contrast, the proportion of the energy consumption for the railways is very low at 2.5 % and it was basically the same in 2004 and 2006.

We find that the energy consumption structure of the various modes of transportation in China during the late 1990s is quite similar to that of Japan during the mid-1960s, which represents the beginning of the country's economic expansion. Road transportation is the key energy consumption mode of transportation and there is a vast potential for energy savings.

(3) In terms of energy savings, giving priority to the development of public transportation systems and new energy-efficient vehicles is an effective way to reduce transportation energy consumption.

U.S. transportation demand-management policies to guide public transportation projects have reduced transportation energy consumption. The automobile's unit energy intensity in road transportation has dropped from 20.7 kgce per 100 vehicle-kilometers in 1970 to 12.34 kgce per 100 vehicle-kilometers in 2007. The energy intensity per unit of light trucks has dropped from 27.92 kgce per 100 vehicle-kilometers in 1970 to 15.46 kgce per 100 vehicle-kilometers in 2007. These are large declines, which show that the use of technology and transportation demand-management measures has created a lot of potential for energy savings in terms of road transportation. The civil aviation passenger transportation energy intensity has been reduced from 23.01 kgce per 100 passenger-kilometers in 1970 to 7.05 kgce per 100 passenger-kilometers in 2007. However, it has been decreasing slowly after 2000. The railway passenger transportation energy intensity has fluctuated between 5 and 7 kgce per 100 passenger-kilometers. This indicates that the technology tends to be mature and the railway's energy-savings potential is quite limited. With the guidance of transportation demand management policies, more people have chosen public transportation, resulting in its energy intensity to rise from 71.17 kgce per 100 vehicle-kilometers in 1970 to 88.17 kgce per 100 vehicle-kilometers in 2007, with some fluctuations. However, the overall passenger transportation energy intensity in the United States has declined (Fig. 5.11).

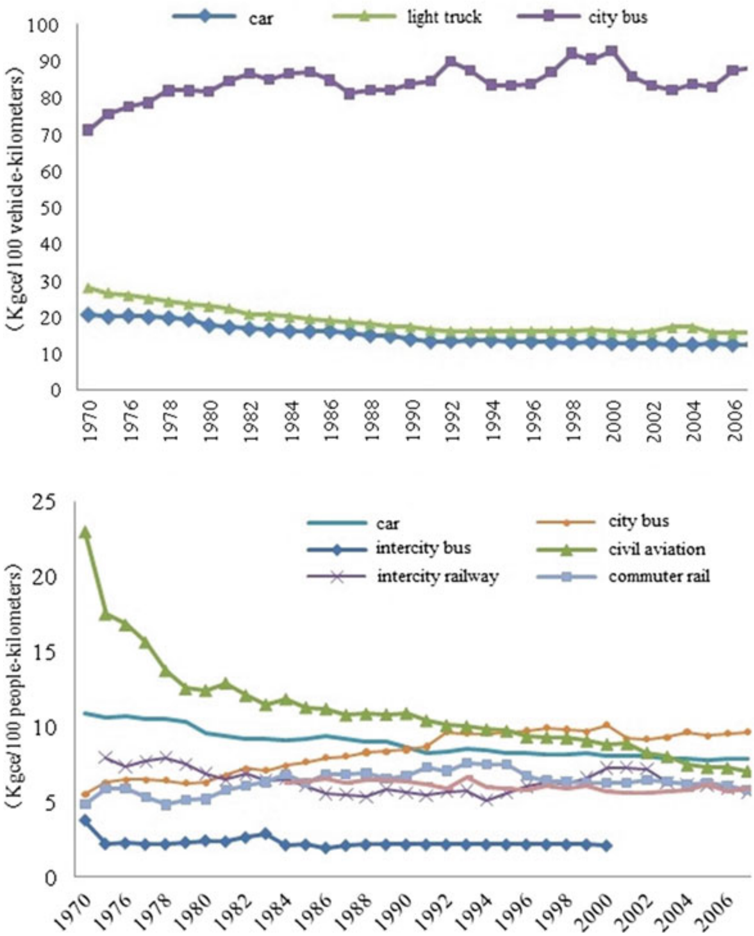

Fig. 5.11 Passenger transportation energy intensity in the US (1970–2007). *Data source* ORNL (2009)

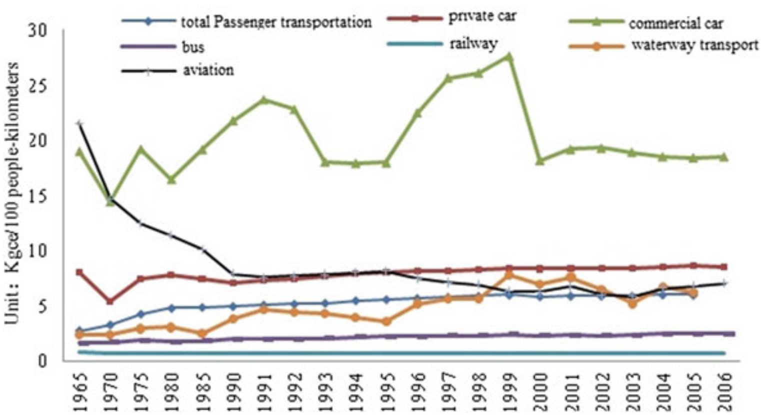

Fig. 5.12 Passenger transportation energy intensity in Japan (1965–2006). *Data source* IEEJ (2008)

Japan has vigorously developed its public transportation and has encouraged the purchase of new energy-efficient vehicles, reducing transportation energy consumption. From Fig. 5.12, we can see that Japan's passenger transportation energy intensity shows the following features. First, the intensity of public passenger transportation, including rail transportation is minimal. To this end, the Japanese government has developed public transportation, including the "Shinkansen," and saved a lot of energy. Second, the energy intensity of passenger cars is the highest. As a result, the government has implemented a number of policies to encourage the use of new energy-efficient vehicles, which have low energy intensities and low emissions, and have stimulated purchases through such measures as taxation, road rights, laws, and regulations to reduce energy consumption and the emission of pollutants. Third, the passenger energy intensity by sea and air has been relatively stable. The ocean transportation energy intensity first increased and then showed a downward trend while the air passenger energy intensity has shown a steady decline. This indicates that due to technological progress and the application of government economic levers; more and more residents have chosen the convenience of public transportation, thus directly reducing the amount of energy consumption.

The EU has encouraged the use of new energy-efficient vehicles with stringent fuel standards to conserve energy. From 1990 to 2007, through technical innovations, a large number of energy-saving and new energy-efficient vehicles, including diesel-powered and hybrid vehicles, have been put into service and these measures have continuously improved the energy efficiency of passenger cars in the EU countries. The fuel consumption efficiency of the EU-27 region has dropped from 8.48 L per 100 km on average in 1990 to 7.22 L in 2007, an average annual decline of 0.9 %. The EU-15 region's fuel consumption for new cars fell from 7.57 L per 100 km on average in 1990 to 6.35 L in 2006; an energy efficiency increase of 1.0 % on average (Table 5.11). With the EU's further stringent requirements of fuel

Table 5.11 Changes in the energy efficiency of passenger cars in the EU countries (1990–2007)

Country	1990	1995	2000	2002	2003	2004	2005	2006	2007	Change rate (%)	Average annual change rate (%)
Vehicle in use											
EU 15	8.39	8.01	7.78	7.65	7.55	7.49	7.42	7.37	–	–	–
EU 27	8.48	8.20	7.93	7.76	7.62	7.50	7.41	7.31	7.22	−14.9	−0.9
New car (test)											
EU 15	7.57	7.69	7.04	6.71	6.63	6.52	6.42	6.35	–	–	–

Unit Liters per 100 km

technology standards and the introduction of policies to encourage new energy-efficient vehicles, the fuel consumption of passenger vehicles per 100 km is expected to decline further.

5.1.3.2 The International Comparative Study of the Transportation Energy Consumption Structure: Findings and References

(1) International comparison and revelations of the transportation energy consumption structure.

We attempt to summarize the general laws of the total energy consumption of both the Chinese and foreign transportation sectors and their structural evolutions to provide some inspiration and reference points for our transportation mode selections and structural optimization recommendations.

(a) The growth of transportation energy consumption is an inevitable trend of social and economic development.

The history and experience of foreign transportation development shows that the rapid development of the economy and society, as well as the growing needs for travel safety, comfort and convenience, the rapid increase in transportation energy consumption, and the sector's increasing proportion of the total for society as a whole is an inevitable trend. In addition, when economic and social development reaches a certain stage, transportation will become the most important sector in terms of energy consumption (especially oil). For example, in the US, Japan, and EU, the proportion of the transportation industry in terms of the total energy consumption is 29, 24, and 31 %, respectively, while that in China is only 7.8 %; thus, there is a huge scope for growth. In particular, in terms of the main types of energy consumption, oil consumption in the transportation sector in China accounted for 33.62 % of the total in 2007. According to the predictions of the State Council Development Research Center, China's transportation industry in 2010 and 2020 will reach 138 million tons and 256 million tons, respectively, or 43 and 57 % of the country's total oil consumption. If we do not take remedial measures to effectively strengthen our transportation energy-saving measures, transportation development may face severe energy constraints, which will produce serious adverse effects on our national energy security, as well as the sustainable development of our economy.

(b) Optimizing the structure of transportation is the main direction for achieving transportation energy savings.

Choosing reasonable modes of transportation for development and optimizing the combinations (i.e., the ratio structure) between the various modes have important impacts on the sector's total energy consumption. The differences in the national integrated transportation networks also determine the differences in the energy consumption structure of the various modes of transportation. Of the total energy consumption for transportation in the US in 2007, road transportation accounted for about 80 %, shipping occupied 5.6 %, railways were 2.3 %, civil aviation represented approximately 9 %, and pipelines were 3.2 %. In Japan, road transportation accounted for 86.8 % while shipping accounted for 6.1 %, railways were 2.3 %, and civil aviation represented 4.8 %. For China, energy consumption of the road transportation subsector in 2005 accounted for 59.4 % while that for shipping accounted for 14.4 %, railways were 16.7 %, and civil aviation was 9.6 %. Today, there are some serious problems such as the sluggish pace of conversions, an irrational structure, and a lack of reasonable guidance in the use of private cars among the various modes of transport. Therefore, in terms of future energy savings in the transportation sector, it is crucial to optimize the transportation structure.

(c) The use of economic levers to encourage technological innovation as an effective means of transportation energy savings.

Encouraging new types of energy and new technologies through technological innovations in the transportation sector are crucial ways to achieve energy conservation. At present, the cost of new technologies is relatively high, so the government should apply some economic leverage to encourage people to use alternative energies and new technology. To promote the purchase of new energy-efficient vehicles, Japan started implementing a "green tax" on April 1, 2009, which applied to pure electric vehicles, hybrids, clean diesel cars, gasoline-fueled cars, and other recognized low fuel consumption vehicles. The first three types of vehicles have been categorized as "the next generation cars" by the Japanese government. Purchasing such vehicles allows one to get an exemption from a variety of taxes. The experience of Stockholm in the development of clean energy vehicles mainly includes the following procedures. First, the government guides the consumer and the government's directives guide the market. Second, the government takes a number of measures, such as government purchases and subsidies, emissions taxes, and free parking, to encourage the use of clean energy vehicles. At present, economic incentives for clean energy vehicles in China are still in their infancy and need further improvement and strengthening.

(d) Building sound transportation energy statistical systems are a strong guarantee for transportation energy savings.

In terms of the proportion of the transportation sector's energy consumption in the developed countries and regions in last few decades, it shows a slight upward trend that has gradually stabilized overall. The proportion for the US is approximately 27–29 % and that for Japan is about 16–25 %. For the EU, it is about 27–31 %. From the China Statistical Yearbook, China Energy Statistical Yearbook, and other official statistical data, the proportion of total energy use by the transportation, storage, and postal industry is approximately 7.2–7.8 %. According to the data from the relevant experts and scholars and in accordance with international standards, the proportion of the transportation energy consumption in China from 2000 to 2007 was about 16.3–17.2 % (Wang 2008).

China's current transportation energy consumption statistics only cover the aspects of operating the transportation equipment, without including the large proportion of energy consumption by private vehicles. Considering the differences between domestic and international statistical standards, we estimate and correct China's transportation energy consumption in accordance with international standards (mainly private transportation). The proportion of energy consumption in the transportation sector relative to the country as whole was approximately 12.8 % in 2005 (Table 5.12).

It can be seen from international experience that automotive and fuel technologies are the main factors of energy consumption and the resulting emission of pollutants. However, there is no uniform standard in the existing statistics about how to identify, compute, and measure them. Government departments at all levels should conduct research and international comparisons, rely on the core factors, and establish a complete set of energy-saving transportation management directives, as well as a system of statistical indicators.

(2) International comparison of the transportation energy intensities and findings

Through a comparative analysis of Chinese and foreign transportation energy intensities, we can summarize some general findings:

Table 5.12 The world's subregional and subsector end-use energy consumption structure in 2005

Country or region	Total energy consumption	Sectorial consumption			
		Industry	Transportation	Civil/commerce/agriculture	Non-energy use
China	890	518 (58.2)	114 (12.8)	208 (23.4)	50 (5.6)
US	1598	386 (24.2)	648 (40.5)	503 (31.5)	61 (3.8)
EU 25	1296	392 (30.2)	372 (28.7)	499 (38.5)	32.6 (2.5)
Japan	351	127 (36.2)	93 (26.5)	121 (34.5)	9.6 (2.8)
OECD	3853	1127 (29.3)	1299 (33.7)	1307 (33.9)	120 (3.1)
World total	6856	2447 (35.7)	2005 (29.2)	2170 (31.7)	234 (3.4)

Unit 100 million tons of oil equivalent (toe); Figures in brackets is the proportion

(a) It is difficult to decrease the passenger transportation energy intensity levels.

From the relative change in the trend of passenger transportation energy intensity levels over the years and the foreign experience, it shows that the passengers' unit energy consumption may change slightly or even show an upward trend, with the continuous improvement in their comfort levels while traveling. From our comparison of the absolute value of the energy intensity indicators, China's passenger transportation energy intensity is lower than that of developed countries. One of most important reasons is that China is a developing country with the largest population in the world. Moreover, another reason relates to the basic national condition, in which the development of the transportation infrastructure is relatively slow. As a consequence, passenger transport in China is often at the expense of safety and comfort (such as the severe overloading of railways, highways, urban transportation networks, etc.). Of course, it cannot be ignored that the statistics of energy consumption in certain transportation sectors (especially roads) cannot be trusted and that the measures used are inconsistent with the international statistical standards. A comprehensive analysis of international passenger energy intensity trends shows that the potential to decrease the passengers' energy intensity is relatively small and rather difficult. In future, China needs to consider the best trade-off between energy efficiency and quality of service.

(b) The ability to reduce the freight energy intensity level is quite large

From the relative changes in the trends of national freight energy intensity levels over the years, the transportation energy intensity level for most countries and regions, such as the US, Japan, and EU has shown an obvious downward trend. The data shows that even for the countries whose freight services and logistics are well-developed, the potential for energy savings is still large. This is an important inspirational message for the future of transportation energy savings in China—through reasonable and effective measures, the country has significant room to reduce its freight energy-intensity levels.

(c) The absolute value of the energy-intensity indicators is closely related to the transportation structure

According to the international comparison of the absolute value of the energy-intensity indicators, the various transportation modes vary.

In terms of highway transportation, road freight energy consumption per unit is lower in China than in most developed countries. This result may be due to severe overloading (especially roads), leading to early damages and reduction in the durability of the transportation infrastructure. This finding is based on information about the loss of state property and public safety hazards. Of course, the accuracy of China's road transport energy consumption statistics and other statistical data distortion factors should be considered.

In terms of water transportation, ocean transportation is international, but national statistics vary and the absolute value of the energy-intensity indicators is not comparable. Besides, the comparison of waterways, roads, railways, and other modes of transportation in integrated transportation systems is poor. Therefore, we focus on an international comparison of inland waterways, in which the developed inland shipping network in the US (especially the Mississippi River) can be used as the benchmark for inland shipping in China (including the Yangtze River, Pearl River, Beijing–Hangzhou Canal, etc.). The evolutionary trend of energy-intensity indictors for inland shipping in the US in recent decades shows an overall U-shaped curve. In particular, the energy-intensity level has increased in recent years due to the rise in the proportion of high value-added goods, greater shipping speeds, and other factors.

From a horizontal perspective, the level of inland freight energy consumption per unit in the US, which can be regarded as the energy-savings benchmark, is lower than that in China. However, one must pay attention to the corresponding differences in their development stages when making comparisons. In addition, in terms of energy consumption per unit value, with the obvious difference between a few large shipping companies (e.g. China Changjiang National Shipping (Group) Corporation) and the large number of individual operations on the inland waterways, the main direction and critical path for saving energy is to adjust and optimize this structure.

(3) Findings based on international transportation energy-saving policies

Developed countries have recently paid great attention to saving energy and increasing energy efficiency to achieve sustainable development and protect the environment. The countries have correspondingly adopted a series of energy-saving countermeasures. Studying the experiences of the US, Japan, EU, and other developed countries in conducting transportation energy-saving measures can help us profoundly understand the role of government in terms of saving energy in the transportation sector and the use of strategic policies and measures in the market economy system.

(a) Improving the integrated transportation system and promoting public transportation are the strategic initiatives for achieving energy savings in the transportation sector.

Different modes of transportation have unique characteristics. Forming an integrated transportation system can effectively improve the efficiency and achieve the objectives of the system (e.g., energy savings) through its advantages in terms of market competition. Internationally, countries have spared no effort to improve their public transportation systems by selecting public transportation as the preferred mode of urban transportation and strengthening the combination of various transportation policies to encourage high-capacity infrastructure and increase intercity passenger traffic. Moreover, the countries have vigorously developed multi-modal forms of transportation and improved conveyance loading rates.

In addition, the consumption patterns of the transportation energy sector have a strategic impact on a country's transportation infrastructure and the sector's development. By comparing the transportation energy consumption patterns among all travel modes in Japan and the US, rail transportation represents approximately 27 % in Japan while private cars account for 87 % in the US. The average displacement of the family car in Japan is 1.2 L, of which 34 % is less than 0.66 L. However, in the US, the displacement ranges from 2.0 to 2.5 L, accounting for 30.1 % and those with a displacement greater than 4.5 L account for 20.6 %. Therefore, Japan can be seen to embrace a typical energy-saving pattern while the US belongs to a typical luxury-consumption pattern (IEEJ 2008).

(b) Scientific and technological progress is a powerful driving force for energy savings in the transportation sector

Scientific and technological progress is not only key to transportation development but also one of the most important means of energy conservation in the transportation sector. Many countries focus on advanced science and technology to enhance their ability to save energy. First, by continuously improving vehicle performance and focusing on improving energy efficiency, thereby reducing energy consumption; second, by strengthening research on alternative fuels and renewable energies and reducing dependencies on traditional energy sources. Developed countries attach great importance to new energy sources and alternative energy technologies to reduce their dependence on fossil fuels. Third, taking full advantage of information technology (IT), developing intelligent transport systems (ITS), and promoting IT to further improve the management of the transportation system, which includes the transportation organizations and management systems, network optimization, operations monitoring, and so on to improve transportation efficiency and achieve the energy efficiency goals.

Related research shows that by 2030, transportation's CO_2 emission-reduction techniques will include hydrogen fuel-cell vehicles, modular hybrid vehicles, a transportation system with changing traffic patterns that also interact with such changes, and so on (IEA 2009; NDRC-ERI 2009; 2050 China Energy and Carbon Emissions Research Team 2009). International experience shows that the application of IT has great potential for energy savings in particular and that the effect is significant. It is possible to achieve an emissions reduction rate of 15 %. In terms of logistics, the emissions reduction in CO_2 is 15.2 million tons, with a value of $3266 (2050 China Energy and Carbon Emissions Research Team 2009). Japan's New Energy and Industrial Technology Development agencies clearly include energy-saving technological and strategic research, automotive lightweight carbon fiber composite materials development, technological development of a new generation of low-emission vehicles, and environment-friendly small aircraft engine research and development (2050 China Energy and Carbon Emissions Research Team 2009; Japan's Energy Conservation Center 2008) as the key areas of support in their annual budgets.

Direct government investment drives the other investments of related entities in transportation technology research, which contributes to the promotion of leapfrog development in the transportation sector of developing countries. This process enables the transportation sector to convert from resource- and energy-dependent development to innovation-driven development. The key areas of energy efficiency investment are the development of energy-saving and environmental protection technologies (especially hybrid and fuel-cell vehicles), as well as their technical equipment; the optimal combination of infrastructure for the various transportation modes (such as integrated transport hubs); establishment of modern information and communication technologies on the basis of planning and management techniques; construction of intelligent transportation systems; and development of modern logistics approaches that enhance the overall level of transportation energy-savings at the macro-management level.

(c) To conduct transportation energy conservation in an orderly manner, it is essential to strengthen the supervision of government in terms of energy savings.

Developed countries have paid great attention to upgrading their institutions and establishing powerful energy management agencies to strengthen the management of energy conservation by their governments. The management of energy savings varies throughout the world and is closely linked with a country's political system and cultural traditions. It is generally believed that most countries with market economies adopt market mechanisms with the support and intervention of government. In contrast, a small number of countries adopt a model of government intervention, which is supplemented by the market mechanism. For example, the Australian federal government implemented a management model that "encouraged, guided, and propagated mandatory regulations and policies to promote energy-saving development and environmental protection." Further, with an oriental cultural background, Japan developed a management model of "restrictive policies + supportive policies + information services."

In addition to its market-driven nature, energy conservation also includes the quality of public utilities, which are subject to market failures. The experience of the US, EU, Japan, Australia, and other market economies has shown that energy savings must be promoted by the government, where institutions are responsible for energy conservation. With continuous strengthening of government functions in the field of energy savings, a variety of controls should be used to intervene in the market. For example, the U.S. Department of Energy is responsible for the establishment of the State Energy Conservation Office, which currently heads the energy efficiency and renewable energy programs. In Japan, the Department of Energy Savings within the Office of Resources and Energy takes responsibility for these matters under the Ministry of Economy and Industry. The Australian government has established a sustainable energy department, which is working on improving energy efficiency and combating climate change. Most developed countries have perfected energy-saving management systems. On the one hand, they set up specialized agencies to implement national and local energy efficiency policies. On the other hand, through the establishment of a favorable policy environment and incentives, the energy-saving intermediaries are given complete access and support, and they represent the link between the government and marketplace.

(d) Energy efficiency regulations are important in guaranteeing the promotion of rational and efficient uses of energy in the transportation sector

Improving energy efficiency and giving conservation priority have become an important part of the national energy strategy. Japan, the US, UK, Sweden, Switzerland, Italy, South Korea, and other countries have used legislation to develop energy-saving laws and regulations at both the national and local levels. Japan developed the Act on the Rational Use of Energy in 1979. The US, EU, Japan, Brazil, South Korea, and most countries with market economies have established energy efficiency standards and classification systems as important forms of energy-saving regulation. Energy efficiency standards are divided into two categories: mandatory and voluntary standards. The former represents the minimum energy efficiency standards for related products, equipment and systems that are implemented by laws and regulations. The latter encourages manufacturers and consumers to achieve higher energy efficiency standards through financial incentives, which is a form of market behavior. The energy policies and energy efficiency standards mentioned above are updated every three to five years, in response to the continuous development of energy-saving technologies. These energy efficiency standards and classification systems not only achieve the purposes of limiting energy-intensive products and encouraging low-energy consumer products in the marketplace but also provide quantitative and measurable indicators for the formulation of energy-saving incentives. Energy efficiency standards and classification systems in the US, Japan, Australia, and some European countries have had some positive energy-saving effects and have become a means of reducing international trade barriers. In addition, they are important in measuring the scale of various energy-saving incentives at the same time.

(e) "Green" fiscal policy is an efficient means to guide the energy-efficient transportation sector

International experience shows that "green" fiscal policy has a considerable impact on energy-saving decision making in the transportation sector. Therefore, to accelerate the development of sustainable transportation, taxation policy is particularly important. In this regard, the developed countries have a wealth of successful experience to draw upon (Table 5.13).

Among these options, the fuel tax is generally considered to be the most effective means of fiscal adjustment. At present, it is common practice for the developed countries to use a fuel tax. As for vehicle tax and fee policies, Singapore, Denmark, and Japan are typical examples. In terms of highway tolls and parking charges, it is common for the developed countries to implement tolls in the urban areas to control traffic during peak hours and to reduce the heavy-traffic areas. Moreover, these countries also use electronic detection methods to capture infractions, especially in cities such as London and Singapore. For tax relief associated with new, clean-energy, and energy-efficient automobiles, this option is more common in countries such as Japan, Denmark, and Germany.

Table 5.13 Taxation policies related to sustainable transportation taxation policy

Category	Level I	Level II	Level III
Fuel tax	Gasoline/diesel tax (Poland)	Carbon tax (Sweden)	Fuel taxes based on the requirements of environmental protection (no paradigm)
Auto tax	Annual tax based on vehicles (European Union)	Tax breaks of new clean energy energy saving car (Japan, Germany, Denmark)	Carbon dioxide and smog emissions fee based on external factors (UK, Denmark)
New car incentives	Clean car discount (Japan, the United States)	High fuel consumption tax (London, England)	Vehicle charging + Discount (Austria)
Road charging	Road charging/Hot Lane (California in the United States)	Congestion charge (London, England)	Road pricing completely based on the externality (Singapore)
User fee	Parking fee (California in the United States)	Parking lot replacement fee (South Africa, Iceland, Canada, Germany)	Parking demand management (United States)
Automobile insurance	Punishments for not paying compulsory insurance (Britain, the United States)	Car insurance special tax (France)	Insurance that charge according to the moving and according to the oil pump (no paradigm)
Car motorcade incentives	Public motorcade that cost efficiency, clean, fuel efficient (Canada)	Incentives to promote clean and fuel efficient vehicle for company (UK)	Rewards for environmental protection car rental (no paradigm)

The above data are taken from Gordon (2005)

5.1.4 *International Comparison of Energy Consumption and Emission Reductions*

Based on the above comprehensive analysis of energy-saving policies for both domestic and international transportation, we can determine the main future orientations of transportation in China.

(1) Optimize the transportation structure and build an integrated energy-efficient transportation system

At present, the various modes of transportation are in a period of great expansion in China. Building a comprehensive transportation system has great significance not only for the transportation industry itself but also for the quality and sustainability of the economic and social structures. Therefore, we must accelerate the construction of energy-efficient transportation systems in China in accordance with the principle of "using water transport when appropriate, using road transport when appropriate, and using air transport when appropriate" and giving full recognition to the comparative advantages of railways, highways, waterways, airports, and pipelines. This approach is a good way to optimize traffic routes and transportation resources, strengthen transportation links and integrated transportation hubs, develop multimodal transportation networks, and accelerate the formation of a convenient, smooth, efficient, safe, and integrated transportation system. In addition, we should coordinate the various modes of transportation, rationally allocate and effectively use the transportation resources to take complete advantage of an integrated transportation system, and rationally choose between the various modes of transportation in accordance with their economic and technological characteristics, their divisions of labor and complementarity, and their advancements in such performance features as coordination, optimization, and the seamless and zero-distance transfers between modes of transport. All these measures can work together to improve the overall efficiency and effectiveness of China's transportation system.

(2) Promote "green" consumption patterns and give priority to public transportation

Because of the basic national conditions in China, such as very large population and relatively few resources per capita, we must accelerate the formation of a consumption–savings pattern, with the inevitable choice of giving priority to public transport development. To increase the awareness of energy conservation by the public, we should effectively increase our publicity and educational efforts, with a focus on strengthening our guidance of the public, actively promoting the concepts of "green" transportation, promoting public transportation and non-motor vehicles, and guiding people to purchase and use energy-saving and environment-friendly vehicles. Further, other measures need to be taken, such as fully implementing the government's priority for public transportation, increasing financial investments and tax incentives, exploring dedicated or priority channels for urban public transport, and creating public transportation and signal-priority systems. Moreover, we still need to vigorously develop the public passenger service system and focus on improving the quality of passenger services, as well as use diversified, high-quality transportation services to encourage travelers to choose public transportation and actively promote switching from private transportation to public transportation. Lastly, strengthening urban public transportation systems and rural highway passenger hubs, accelerating the integration of urban and rural passenger networks, and increasing policy support for more rural road infrastructure can enable people to fully enjoy the comforts and pleasures of public transportation while reducing the energy consumption levels of society as a whole.

(3) Improve the organization and management of the transportation sector by enhancing its effectiveness and efficiency

Modern logistics is an important area in the development of a new transportation service industry and in the transformation and upgrading of the traditional freight industry. The transportation sector should, at all levels, earnestly strengthen the regulatory functions of the transportation marketplace; accelerate the establishment of a unified, open, fair, competitive, and orderly transportation market; actively develop modern logistical procedures; and improve transportation efficiency and service levels. Further, it needs to (i) develop third-party logistics, (ii) guide the coordination and cooperation between the freight business and commercial enterprises, (iii) vigorously expand the warehousing, distribution, and other service functions, (iv) expand the area of business services, (v) play an important role for the transportation companies in the logistics supply chain, and (vi) promote the use of various transportation modes during the transition towards more modern forms of transport. In addition, it should promote large-scale, intensive, petals modes of transportation and improve transportation scale and the degree of organization. Steps that need to be implemented include boosting the advanced mode of transportation, such as transportation with dumping trailers, multimodal transportation and van transportation, enhancing cargo organization and capacity allocation, efficiently using backhaul capacity to improve cargo loading rates, and reducing the energy consumption level of the transportation sector.

(4) Strengthen the research and development of energy-saving technologies and innovations to raise the overall level of energy efficiency in the transportation sector

The government must actively guide and promote market-oriented, energy-saving technology innovation systems based on enterprises and production and study the transportation industry. Focusing on global, directional, and integrated key technical issues, the government should vigorously promote the transportation sector's energy-saving technological innovations, encourage original and unique innovations, strengthen the integration of various innovations, and absorb renovation. It is also important to rapidly develop clean and efficient diesel vehicles, accelerate the popularity of fuel-efficient cars, promote renewable and alternative energy sources, and optimize the transportation energy consumption structure. Moreover, other measures that need to be taken include integrated applications with IT, better management and technology to increase the limit, paying more attention to intelligent transportation features, logistics, and other aspects of technology research and development, strengthening basic research, and overcoming key technological bottlenecks and applying the results universally to promote high-tech applications in the transportation sector. Further, it is necessary to promote the development of industry information systems and to encourage the transportation companies and enterprises to use modern information technology so as to enhance their core competitiveness and improve the overall operating efficiency of the transportation system. Furthermore, we need to strengthen the promotion of transportation energy-saving and technological achievements by actively using new technologies and new materials, as well as new equipment. Moreover, we need to encourage the application of innovative techniques and establish and improve the effective mechanisms for the promotion of new achievements, enabling further perfecting and stimulating development of the standard system of energy-saving technologies.

As a result, we can fully promote the progress and application of new energy-saving technologies and raise the overall energy efficiency of the transportation sector.

(5) Strengthen the supervision and administration of energy savings and improve the energy-saving regulations and service capabilities of the transportation sector

It is essential to accelerate the development and improvement of the legal system that is related to energy savings, as well as the standards of the transportation sector. We need to promote the role of planning and policy guidance to improve the transportation development strategy and the planning policy system, strengthen the transportation energy-saving special planning and policy systems, and strengthen the convergence and coordination of the relevant planning organizations. Besides, the government should use its funds as a guide by actively adjusting its transportation investments and increasing its funding for energy savings. Also of great importance is the establishment and improvement of a comprehensive and modern transportation management system, which emphasizes an integrated transportation planning, policymaking, and legal system that coordinates the development of various modes of transportation. We should also carry out steps such as strengthening the administrative law enforcement departments, making transportation energy conservation the focus of the industry regulator and increasing the scope of monitoring. Furthermore, other measures include building long-term energy-saving mechanisms and product certification systems, stepping-up research projects to build the transportation energy-use statistical monitoring and evaluation systems, establishing and improving the energy-saving targets and responsibility systems, promoting open government, developing e-government, and working together with all aforementioned parties to improve overall management efficiency.

5.1.5 Summary

In this subsection, we focus on the energy-consumption characteristics of the transportation sector in China, an analysis of the factors affecting the transportation energy demand, a comparison of Chinese and foreign transportation energy consumption patterns, and energy-saving and emission-reduction measures, as well as policies. After a systematic study of these important issues, we make the following main conclusions:

(1) The study analyzes the main features of the evolution of total energy consumption in China, as well as its structure and intensity within the transportation sector. From the sector's structure by energy type, transportation consumes mainly petroleum products. In 2007, oil consumption accounted for 86.2 % of the total. In terms of the trend of changes in energy consumption, the total energy consumption of transportation, especially roads, has been growing rapidly. From the various modes of transportation, road transportation

energy consumption grew rapidly and accounted for the absolute measure of total momentum. From the energy intensity of transportation, the total energy consumption per unit has declined, but the added value per unit of energy consumption has risen. Furthermore, we analyzed and compared the energy intensity characteristics of highways, waterways, railways, airports, and other modes of transportation. The results showed that in addition to road transportation, waterways, railways, civil aviation, and other modes of transportation energy experienced a greater degree of decline in terms of intensity.

(2) This study presents a systems-analysis framework of the factors influencing energy intensity within the transportation sector and analyzes the main factors of energy savings from three perspectives: structural energy savings, energy-saving technology, and energy conservation management. Transportation energy savings stem from a vast and complex system of engineering, and they are affected by many factors, which generally fall into three categories: structural, technical, and management factors. Among these categories, structural factors include the integrated transportation network, transportation infrastructure, transportation equipment, transportation enterprises, and energy consumption. Technical factors include the technical performance of the transportation equipment, transportation and equipment operators, and state of technology currently in use; they also include the energy-saving technologies (products), advanced energy technologies, and information technology applications. Managerial factors include the level of transportation efficiency, traffic-flow management, the management of transportation organization, such as the drivers' experience in terms of eco-driving, and transportation energy-saving regulations, standards and incentives, as well as institutional mechanisms.

(3) We conduct a comparative study of the Chinese and foreign transportation sector's energy consumption. The study analyzes the total amount and structure of transportation energy consumption in the typical developed countries and regions, including the US, Japan, and EU and the evolution and main characteristics of energy intensity. Furthermore, we summarize and explore the world's transportation energy consumption patterns and their histories, providing the basis for selecting China's energy-saving modes of transport. The international comparison of total transportation energy consumption, as well as its structure and historical evolution, together with the main features of energy intensity in typical developed countries and regions, such as the US, Japan, and EU show that (i) transportation energy consumption growth is an inevitable trend of social and economic development, (ii) optimizing the structure of transportation is the main way to save energy in the transportation sector, (iii) the use of economic levers to encourage technological innovation is an effective means to achieve energy efficiency, and (iv) building sound transportation energy statistical systems are a strong means to guaranteeing energy savings. Through a comparative analysis of Chinese and foreign transportation energy intensities, we are able to make some general conclusions: the ability to further reduce the energy intensity of passenger transportation is relatively small and rather difficult, so the future development of passenger transportation

networks needs to consider the best trade-off between energy efficiency and service quality; the ability to further reduce the energy intensity of handling freight is large, even in countries with a high level of freight logistics; and the absolute value of the energy intensity indicators is closely related to the transportation structure. The study summarizes and analyzes the present situation and trends of international transportation energy savings. International experience shows that improving the integrated transportation system and giving priority to public transport development are strategic moves in achieving savings in transportation energy. Scientific and technological progress is a strong driving force for transportation energy savings, and strengthening the supervision and management of energy savings by the government is one of the most necessary conditions for the orderly conduct of transportation energy conservation. The energy-saving regulations and standards are important guarantees for the rational and efficient use of transportation energy while "green" fiscal policy is an efficient type of regulation to guide transportation. On the basis of summarizing and learning from experience from both home and abroad, this section puts forward some main policy guidelines for the future of transportation energy as follows. First, we focus on improving the transportation structure and building an energy-efficient and integrated transportation system. Second, we vigorously advocate "green" transportation consumption patterns and give priority to implementing a public transportation development strategy. Third, we strive to improve the organization and management of transportation by enhancing the effectiveness and efficiency of transportation and production. Fourth, we strengthen the promotion of energy-saving technological innovations, as well as the industrial upgrading of transportation infrastructure. Fifth, we strengthen the supervision and administration roles and improve the regulatory and service capabilities of the transportation sector. Finally, almost all of the data and information reviewed in the study comes from the developed countries, but there is little research on public transportation, cycling, and other "green" travel patterns. In fact, the development of non-motorized transportation is an important way to achieve energy savings, reduce emissions, and promote the construction of a resource-saving and environment-friendly society. This aspect of the transportation industry needs further study.

5.2 Energy Consumption in Buildings

The construction business, which is one of the main driving forces of GDP growth in China, is a major consumer of high energy-consuming products such as steel, cement, and glass. With the higher speed of urbanization after 2000, the Chinese government began pushing for greater activity in the real estate industry, including public buildings, resulting in large-scale architectural projects across the country.

Urban public building construction developed quickly while the real estate industry proceeded at a high speed. The amount of public construction in China was approximately 3.3 billion square meters in 2000, rising to 6.2 billion square meters in 2006 and almost doubling in six years. The consumption of building materials, such as cement, steel, and glass, grew at a rate of 10 % per year, with the building of luxury hotels, theatres, and shopping malls, and this construction required not only a lot of resources but also considerable energy. Wang Tiehong, the chief architect in the Ministry of Housing and Urban Development, pointed out that the energy consumption in construction represented approximately 20–30 % of the country's total energy consumption. If we include the energy consumed during the production of the materials used in construction, then we conclude that the energy consumption in the construction industry represented approximately 46.7 % of the total. Hence, the construction industry plays an important role in reaching the energy-savings goal in the "Eleventh Five-Year Plan."

According to type of use, construction can be divided into civil and industrial buildings. Industrial construction includes the factory workshops and ancillary buildings while civil construction can be divided into residential and public buildings. Public buildings include office buildings (government offices, postal services, etc.), commercial buildings (shopping malls, financial buildings, etc.), tourism buildings (hotels, restaurants and entertainment facilities, etc.), education and healthcare buildings (cultural facilities, schools, scientific research institutions, medical services, sports venues, etc.), communication buildings (telecommunications, radio, etc.), and transportation buildings (airports, train stations, bridges, etc.). We focus on the energy consumption of public buildings in this subsection.

5.2.1 *Definition of Energy Consumption in China's Public Buildings*

5.2.1.1 The Classification and Energy Consumption Characteristics of Public Construction

According to the features of energy consumption, public construction can be divided into large-scale buildings and normal buildings. Buildings with an area of 20,000 m^2 or more and a central air conditioning system are called large-scale buildings, such as luxurious office buildings, large shopping malls, comprehensive commercial buildings, transportation hubs, stadiums, and so on. Normal public buildings have an area of less than 20,000 m^2 and no central air conditioning system.

Large public buildings are a symbol of a modern city. However, due to their special structures and purposes, large public buildings also consume a lot of energy. According to the statistics for China, approximately 4 % of the total area of the buildings in a city is taken up by large public buildings with an area of more than 20,000 m^2, and these public buildings consume more than 20 % of the total energy consumption of buildings. In particular, the electricity consumption per unit area of large public buildings is 10–15 times that of normal civil buildings. Therefore, reducing the energy consumption of public buildings in China is the key to reducing the total energy consumption of buildings in the country.

In fact, energy consumption of buildings should include not only the operational energy consumption after the completion of construction but also the energy consumed during the process of construction. In other words, we should include the energy consumption required to produce the glass, cement, steel, and other building materials. This means that we should account for the building's energy consumption from the perspective of the entire lifecycle of the building. According to the theory of the lifecycle of a building, energy consumption can be divided into five phases. They are the processing and production of building materials, the architectural design and actual construction, occupying and using the building, demolishing the building and disposing of the used building materials. Among the five phases, using the building consumes the most energy. Although there are great differences in the function and lifespan of buildings, the energy consumption during the occupational phase is approximately 70–80 % of the total energy consumption in general. Hence, when we are talking about the energy consumption in the building sector, we essentially mean the energy consumption during use, which includes the energy used for air conditioning, lighting, hot water, office equipment, other devices (electric water supply and drainage systems, etc.), and special functions (e.g., network information centers), with the exception of heating systems.

5.2.1.2 Data Sources and Pretreatment of the Data

To systematically analyze the energy consumption in public buildings in China, we collect the statistics using a bottom-up approach in this subsection. First, we collect the different forms of annual energy consumption in different businesses for every province. Then, we establish a four-dimensional database of the energy consumption of public buildings (by year, business, province and energy type). Using this approach, we can determine the situation in every province, the total public building energy consumption nationwide and all forms of energy consumption (electricity, gas, heat, etc.). We determine the overall development of public buildings using the statistics for the urban population and public construction projects. From the above data, we can also determine the public building energy consumption per capita and per unit area. In addition, we also include the value added data for the tertiary industry to explore the influence of various factors that affect the energy consumption in public buildings.

The sources and pretreatment of the data are as follows:

(1) The raw data comes from the *China Energy Databook, Version 7.0* (Fridley and Aden 2008) and the *China Statistical Yearbook 2009* (NBS 2009).
(2) The types of public building energy consumption include 16 different types of energy such as electricity, heating, oil, liquefied natural gas, natural gas, coal, and bituminous coal.

(3) The conversion of different types of energy. For electricity, it is converted into tons of coal equivalent using the average coal consumption method. For other types of energy, they are converted into tons of coal equivalent using the equivalent calorific value method.
(4) Considering that heating energy used in public buildings cannot be separated from its use in civil buildings, we do not consider heating energy.
(5) We assume that the total public building energy consumption is equal to: transportation, warehouse and postal service energy consumption + accommodation and catering energy consumption in wholesale and retail trade + energy consumption in other industries—transportation, warehouse and postal service fuel consumption.

5.2.2 *Development Tendencies and the Energy Consumption Situation of China's Public Buildings*

5.2.2.1 Status and Trends of Public Buildings

Public buildings are an investment priority of the national infrastructure and with the rapid advance of China's urbanization process, the number of public construction projects has grown rapidly—from 2.8 billion square meters in 1996 to 6.2 billion square meters in 2006. In the short span of ten years, the area of public buildings increased by 1.2 times. However, from 1996 to 2000, the growth in area was relatively slower, at an annual rate of only 4.0 % on average, which is much lower than the growth rate of GDP for the same period. But after 2000, there was rapid growth in public construction, at about 11.0 % per year (in area), except for 2003 and 2004 (as shown in Fig. 5.13).

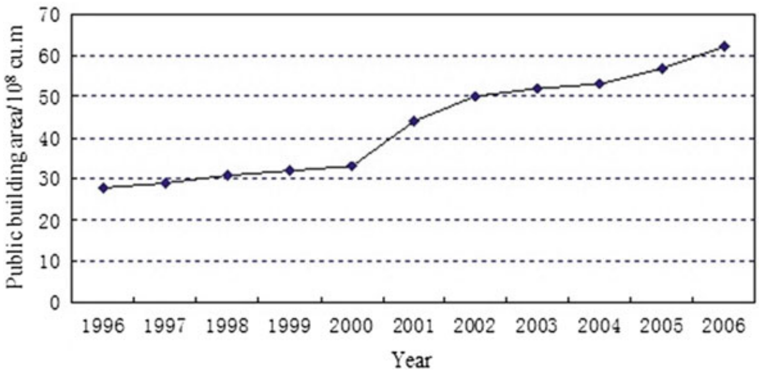

Fig. 5.13 Changes in the area of public buildings (1996–2006). *Data source* Building Energy Conservation Center of Tsinghua University (2008)

Since 2006, when the national “Eleventh Five-Year Plan” emission reduction targets were proposed, the new buildings that implemented the energy conservation mandatory standards have achieved remarkable results. According to data released by the Division of Housing and Urban Ministry in the Office of Energy Savings within the Science and Technology Department at the end of 2009, the cumulative construction area was 4.08 billion square meters, approximately one-tenth of the total, and mainly consisted of government office buildings and other large public buildings. These projects have the capability to save about 36 million tons of coal equivalent per year and reduce carbon dioxide emissions by approximately 93.6 million tons per year. Therefore, public building energy efficiency is crucial to achieving the greenhouse gas emission targets by 2020.

From 1996 to 2006, with the rapid growth in the number of public construction projects in China, the proportion of public construction to the total construction by area is also rising, from 11.33 % in 1996 to 15.46 % in 2006 (Fig. 5.14). In recent years, with the acceleration of urbanization in China, urban construction has maintained a rapid growth rate, increasing from 6.2 billion square meters in 1996 to 17.5 billion square meters in 2006. Therefore, the proportion of public construction in urban areas has decreased from 45.16 % in 1996 to 35.42 % in 2006 (Fig. 5.14). In the future, the annual new construction in China will reach 16 to 20 billion square meters. In 2020, the new construction will be close to 20 billion square meters (Han 2009). Therefore, according to the proportion of public buildings, about 30 million square meters of public buildings will be added by 2020. If the current energy efficiency standards in China are not strictly enforced, then the energy supply is going to face tremendous pressure.

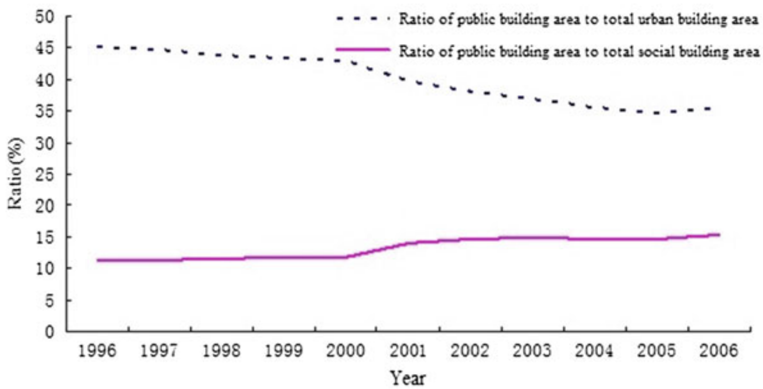

Fig. 5.14 The respective ratios of public construction in the urban areas and in China (1996–2006). *Data source* authors’ calculations

5.2.2.2 The Total Energy Consumption Characteristics of Public Construction

Public construction in China accounts for only 10–20 % of the total construction sector, but its energy consumption is more than 30 % of the total construction energy consumption. Therefore, public construction is a big energy consumer. For example, approximately 4 % of the urban construction consists of large-scale public buildings that are more than 20,000 m^2. However, its energy consumption accounts for more than 20 % of the total and power consumption per unit area is 10–15 times that of ordinary residential buildings.

Due to differences in the statistical measures of various studies, the proportion of building energy consumption to the total energy consumption varies slightly, but it is generally between 20 and 30 %. In other words, the more the number of lifecycle phases that are included in the building energy consumption, the higher the proportion of construction energy consumption to the total consumption of the country as a whole. As mentioned above, here we only take the energy consumption during the process of construction, so the proportion of the total construction energy consumption to that of the country as a whole is relatively lower. As shown in Fig. 5.17, for the period from 1996 to 2006, the proportion of public building energy consumption in the construction industry fluctuated widely while the proportion of construction energy consumption to the total for the country as a whole changed only slightly, remaining at approximately 20 %.

China's public construction growth from 1996 to 2006 was relatively slow, representing approximately 11 % of the total construction sector (Fig. 5.14). However, public building energy consumption grew relatively faster, from 0.69 million tons of coal equivalent in 1996 to 0.87 million tons of coal equivalent in 2000. The proportion of the total building energy consumption increased from 24.27 to 30.65 %, or approximately 6.4 % (Fig. 5.15). After 2000, China

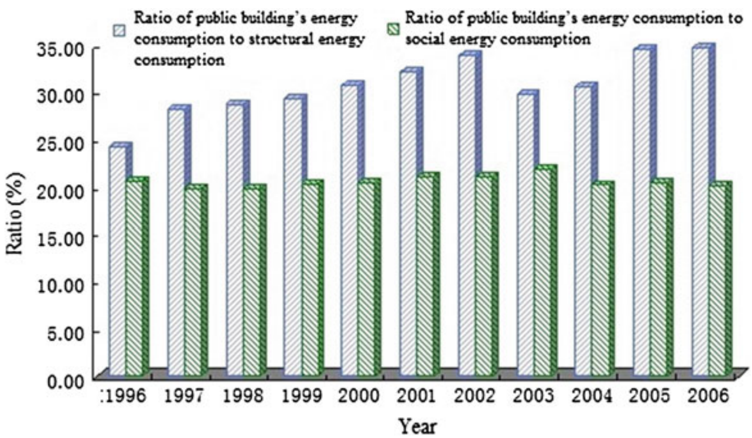

Fig. 5.15 The proportion of public building energy consumption to the total construction energy consumption (1996–2006). *Data source* Authors' calculations

accelerated the process of urbanization and its local governments constructed office buildings and public service facilities, so the country's public building program experienced rapid growth (excluding 2003 and 2004), which will inevitably lead to a rapid increase in the energy consumption of public buildings. Public building energy consumption in 2006 was approximately 171 million tons of coal equivalent and during the previous 10-year period of public building construction, annual energy consumption increased by about 1.5 times. Therefore, public building energy consumption in China shows an overall trend of rapid growth.

In 2006, public construction accounted for 15.46 % of the total construction sector while its energy consumption accounted for 34.59 % of the total construction sector. As a result, public construction is the key for energy savings in China's construction sector. Moreover, with rapid economic development and improvement of the people's living standards, China's building energy consumption will continue to increase and the country's buildings are expected to experience major growth in energy consumption over the next 20 years. Therefore, promoting the development of energy-saving technologies and "green" buildings, particularly in terms of public building energy efficiency, will play a key role in meeting China's target for carbon dioxide emissions; that is, a reduction of 40–45 % per unit of GDP by 2020.

5.2.2.3 Characteristics of Changes in the Energy Consumption Structure of Public Buildings

(1) The structure of public building energy consumption is gradually becoming optimized, with the rapid growth of the electricity share and the quick decline of the coal share.

The energy consumption structure of public construction in China changed greatly from 1996 to 2006. Before 1999, the share of electricity in the energy consumption structure was less than 60 %, mainly because most of the heating systems of the public buildings in northern China are boilers in which the share of coal has stayed above 35 %. After 2000, a large number of new public buildings were constructed and air conditioners and electric water heaters gradually replaced the traditional boilers for heating and hot water. Therefore, the energy consumption structure changed significantly. The electric power share grew rapidly to more than 65 %, the coal share was reduced to below 20 %, and the share of solar and other energies grew to about 15 % (as shown in Fig. 5.16). With the continued rise of energy-saving technologies and "green" buildings, the public building energy consumption structure will be further optimized. Thus, optimizing the structure of public buildings is crucial to optimizing the structure of construction energy consumption, as well as that of total energy consumption in China.

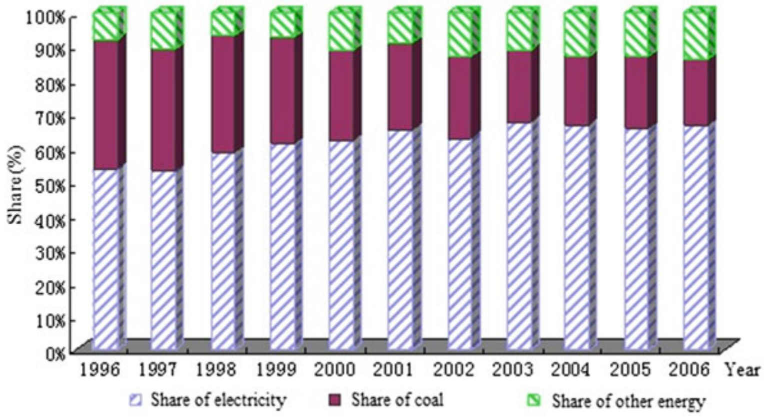

Fig. 5.16 Structural changes in the energy consumption of public buildings in China (1996–2006)

(2) The average annual electricity consumption per unit has grown quickly and public buildings have a large potential for energy savings.

Public construction in China was approximately 2.8 billion square meters in area in 1996 and the annual power consumption was 92.4 billion kWh, or 33 kWh/m^2 per unit. In 2006, public construction reached 6.2 billion square meters and the annual electricity consumption was 281.3 billion kWh, or 45 kWh/m^2 per unit (large-scale public buildings consume about 125 kWh/m^2 or even higher), an increase of 36.4 % since 1996. It is obvious that not only the total power consumption but also the average annual power consumption per unit has exhibited a rapidly increasing trend. Therefore, there still exists a large energy-saving space and potential in terms of public construction.

(3) The energy consumption structure of public buildings is significantly better than that of ordinary buildings, so there is a huge energy savings potential.

According to statistical data, the ratio of public construction energy consumption to that of total construction in China was ranging from 25 to 35 % from 1996 to 2006. During the same period, the electric power consumption of public construction accounted for approximately 44 to 48 % of the total electric power consumption in the construction industry (Fig. 5.17), which is much higher than the proportion of total energy consumption. Thus, the energy consumption structure of public buildings in China is much better than that of ordinary buildings. Therefore, reducing the coal consumption ratio of the construction sector and gradually increasing the share of electricity, particular renewable electricity (e.g., hydro), will play an important role in the realization of the country's energy efficiency goals.

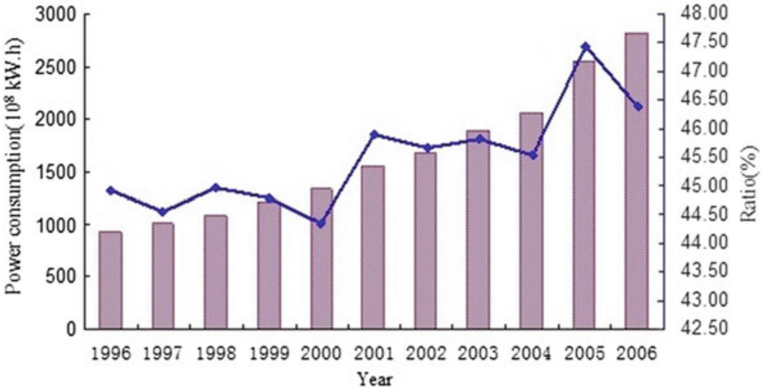

Fig. 5.17 The power consumption of public buildings and its proportion of the total power consumption in the construction industry (1996–2006)

5.2.3 Characteristics of Energy Consumption in Large Public Buildings

Large-scale public building energy consumption is mainly used for lighting, air conditioning, ventilation, office facilities, elevators, domestic hot water, and so on. A survey conducted by Tsinghua University Building Energy Research Center shows that energy consumption per unit area of large-scale public buildings, except those using heat, is quite different from that of more ordinary public buildings, particularly in the following areas (Research Center for Building Energy Conservation, Tsinghua University, 2008):

(1) The energy consumption of large-scale public buildings is much higher than that of ordinary public buildings.

Large-scale public building energy consumption is equivalent to the annual electricity consumption of 90 to 200 kWh/m^2 while that of ordinary public buildings is only 30–70 kWh/m^2. The number of large public buildings in China was about 10,000 in 2004, with a total floor area of approximately 400 million square meters and an energy consumption equivalent to electric power (excluding heat) of 50 billion kWh. The number of ordinary public buildings was in the hundreds of thousands, with a total area of approximately 4.9 billion square meters. Excluding heating, the energy consumption equivalent to electric power was 202 billion kWh. Obviously, the ratio of large public buildings was only 7.5 % while the proportion of their energy consumption was as high as 20 %. The main reason may be that the design of many large public buildings focuses on unique and artistic effects while ignoring the problems of high energy consumption. Therefore, the energy

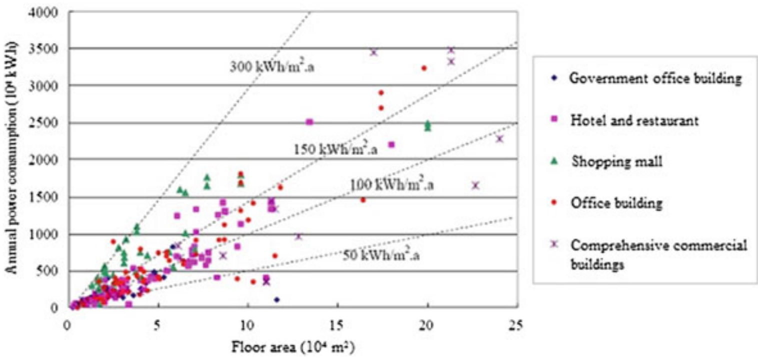

Fig. 5.18 Research of large public buildings in Beijing (2004). *Data sources* NDRC-ERI and THU-CCER (2007)

consumption of large-scale public buildings is like eating a "Big Mac." However, the large volumes of energy consumption and features of centralized management create a huge energy-savings potential and also make such buildings the focus of energy efficiency initiatives.

(2) The energy consumption levels of various types of large-scale public buildings are different

According to the energy consumption characteristics, the general large-scale public buildings can be divided into five categories: government buildings, hotels, shopping malls, office buildings, and commercial buildings. Figure 5.18 shows the annual energy consumption per unit area for these five categories, and the data are from the Energy Research Institute of National Development and Reform Commission and Research Center for Building Energy Conservation, Tsinghua University (2007). The highest energy consumption is related to shopping malls, which reach up to 300 kWh/m^2 while the energy consumption of the government office buildings is the lowest, at about 50 kWh/m^2. Therefore, the government should use the type and function of public buildings as a base from which to set its energy-savings standards and targets.

Through a comparative analysis, we found that large public buildings are very different from the ordinary public buildings in terms of their design and energy consumption features. Due to the neglect of energy savings, which is very important, the energy consumption of large public buildings is much higher than that of ordinary public buildings. Therefore, government officials should attach great importance to this finding; otherwise, the public awareness of energy conservation will not compensate for or offset the energy wasted by these giant structures.

5.2.4 Geographical Differences of Energy Consumption Among Large Public Buildings

(1) Public building energy consumption has very distinct regional characteristics. Public buildings in the economically developed provinces have relatively higher energy consumption.

Since the reform and opening-up period, economic development in the different regions of China has shown great differences, so does the regional level of urbanization and infrastructure construction. Figure 5.19 shows the energy consumption of public buildings in various provinces, autonomous regions, and municipalities directly under the auspices of the central government in 2006. It can be seen that there is a clear imbalance in China's regional public building energy consumption levels. The public building energy consumption in the southeast coastal economically developed provinces is much higher than that of other regions. The central and western provinces, which are economically less developed regions, consume the lowest amount of energy in terms of public buildings. This fully reflects the fact that public buildings and power consumption are directly related to the level of regional economic development. Statistics show that the public building energy consumption in the provinces and municipalities, such as Guangdong, Beijing, Shandong, Shanghai, Zhejiang, Jiangsu, Liaoning, Hebei, Jilin, and Shaanxi is more than six million tons of coal equivalent. In particular, the total public building energy consumption in the six provinces and municipalities of Guangdong, Beijing, Shandong, Shanghai, Zhejiang, and Jiangsu accounts for 43 % of the total public building energy consumption in the country. In Hainan, Ningxia, Jiangxi, and Qinghai, the energy consumption of public buildings is less than two million tons of coal equivalent, accounting for less than 3 % of the total (Fig. 5.19). Therefore, in China's construction sector, energy consumption has very distinct regional characteristics, especially for public buildings.

(2) Public building energy consumption has a close relationship with the value added in the tertiary industry—the more prosperous the tertiary industry, the higher the public building energy consumption.

Energy consumption and the level of economic development are closely related, so the level of regional economic development and the prosperity of the tertiary industry will directly affect the energy consumption of public buildings. Therefore, this subsection focuses on the relationship of energy consumption in public buildings with the value added levels of the tertiary industry (Fig. 5.20).

As can be seen from Fig. 5.20, the energy consumption of public buildings is closely related to the development levels of the tertiary industries in each province and city. For example, in Guangdong, Beijing, Shandong, Shanghai, Zhejiang, and Jiangsu, energy consumption is more than eight million tons of coal equivalent for each area, and they represent the highest public building energy consumption provinces and cities. As the vanguard of China's economic development, the value

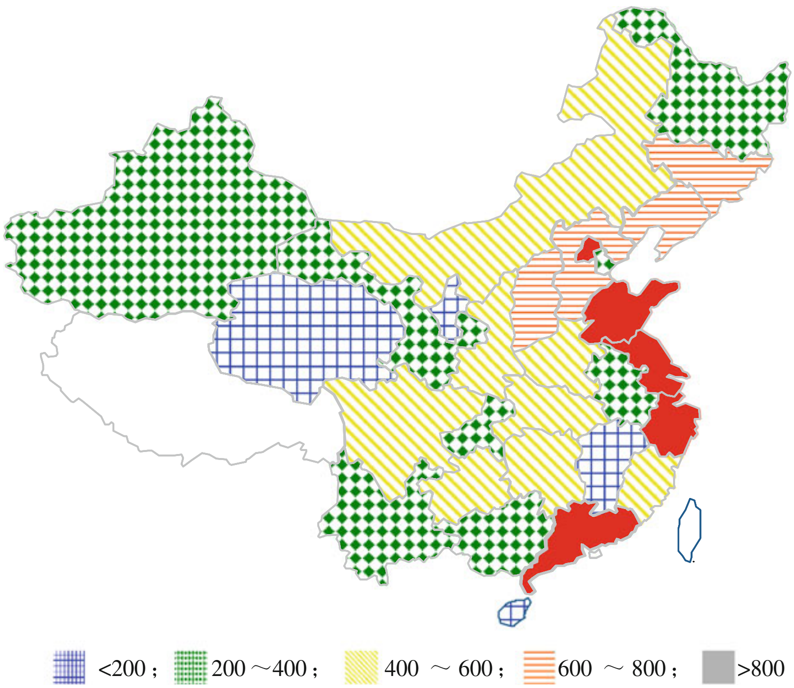

Fig. 5.19 China's regional public building energy consumption (2006). *Unit* 10^4 tce. The figure is a sketch map and does not represent true regions and territories

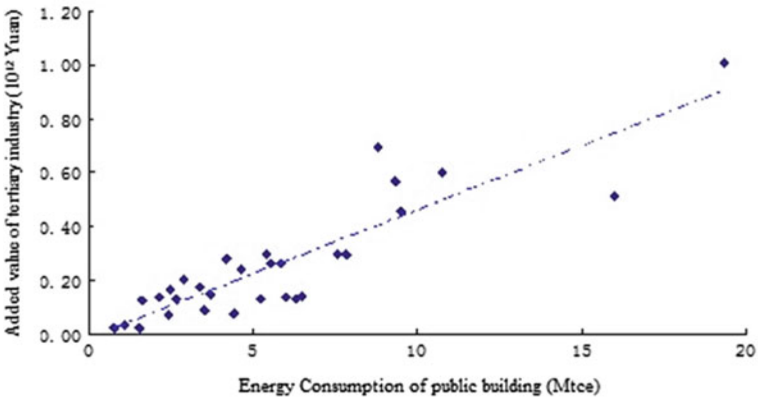

Fig. 5.20 Relationship between public building energy consumption and value added in the tertiary industry

added of the tertiary industry in these six provinces also ranked in the top six areas in China, followed by Guangdong, Jiangsu, Shandong, Zhejiang, Beijing, and Shanghai. The tertiary industry in the developed regional economies experiencing rapid development will inevitably drive the construction of more public buildings. With the increase in income per capita, the frequency of use and energy consumption of public buildings is bound to increase. Therefore, public awareness of energy conservation, especially in economically developed areas, plays an important role in the energy conservation measures employed during construction.

5.2.5 Overall Features of Energy Consumption in Public Building

(1) Public construction is one of the national infrastructure investment priorities. With the rapid advancement of China's urbanization process, public construction also increased rapidly, from 2.8 billion square meters in 1996 to 6.2 billion square meters in 2006. In the short span of 10 years, public construction increased by 1.2 times in area. In addition, public construction energy consumption in China is showing an overall trend of rapid growth, especially during the "Tenth Five-Year Plan" period in terms of public construction energy consumption per capita. Although public buildings accounted for only 10–20 % of the national total construction area, they consumed more than 30 % of the total amount of energy used during construction. Therefore, public buildings are not only a big energy consumer, but they also the key for energy savings.

(2) China's energy consumption structure of public construction projects is gradually becoming more optimized, with rapid growth in the share of electricity consumption and rapid decline in the share of coal consumption. However, because of the rapid growth in the average annual power consumption per unit area, public construction has a large space for energy savings. The energy consumption structure of public construction is much better than that of more ordinary building construction, so a huge potential for energy savings still exists in the construction sector in China.

(3) The energy consumption of large-scale public buildings is much higher than that of more ordinary buildings and the level of energy consumption for different types of large-scale public buildings varies a lot. Although large-scale construction is huge in terms of energy consumption, energy consumption and centralized management features provide huge energy-savings potential, which should be a key feature of future construction projects.

(4) Energy consumption of public buildings in China has very distinct regional characteristics. Public construction in economically developed provinces consumes more energy than public construction in relatively less developed provinces. There is a close relationship between the value added of the tertiary

industry and the energy consumption of the public construction projects. The more prosperous the tertiary industry, the higher is the public construction energy consumption.

5.3 Energy Efficiency in the Electric Power Sector

The electric power industry is the largest energy processing and conversion sector and one of the main industrial sectors in China. At present, 70 % of the consumption of primary energy resources in China is based on coal resources, of which fuel power generation accounts for 50 %. The energy losses merely from generation are more than 60 %, along with another 6.7 % in terms of transmission and transformation. To create a comprehensive index from which to measure the energy utilization technical level and economic efficiency, this section will analyze energy efficiency in the electric power sector in terms of power generation, transportation and distribution, and power system economic dispatch of power system, according to the transfer paths and conversation efficiencies of electric energy (Fig. 5.21).

5.3.1 *Energy Efficiency of Electric Power Generation*

Electric power generation is in the upstream part of the energy industry. It mainly converts the nonrenewable energy resources, such as coal, oil, natural gas, and nuclear energy, as well as renewable energy resources, such as wind, solar, and geothermal energy into electricity. Based on nonrenewable (fossil) energy and renewable energy, there are two major research perspectives: processing conversion

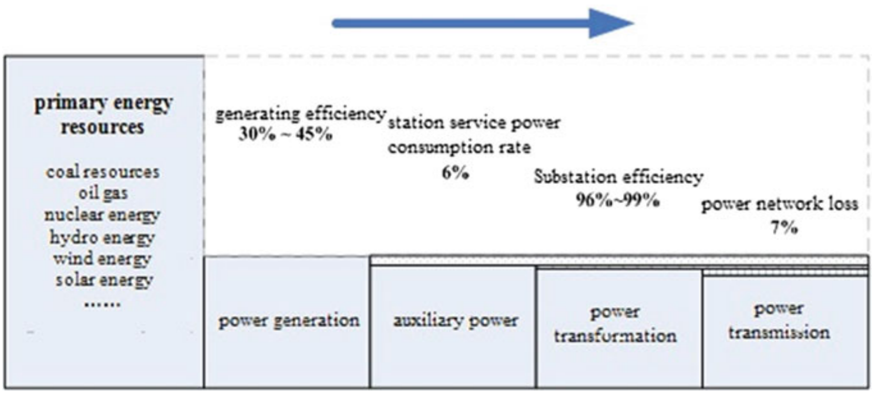

Fig. 5.21 Conversation process and efficiency of the electric power transportation conversation process and efficiency

efficiency and development and utilization efficiency. This subsection will focus on analyzing the processing conversion efficiency of thermal power generation, which plays a leading role in the electric power network in China.

5.3.1.1 The Main Energy Efficiency Index of Electric Power Generation

In 2009, the thermal power installed capacity reached 65,108 million kilowatts, representing three-quarters of the total national power generation capacity, in which most of the capacity was from coal-fired power plants. The diameter thermal power generating capacity reached 3.01 million kilowatts, accounting for more than 80 % of the national generating capacity. The total national coal consumption for electricity generation was 1.40 billion tons, which had been increasing at an annual rate of 6.08 %, and it accounted for 46 % of the national coal consumption (CEC 2010, NBS 2010). The technical economic index, which heat-engine plants measure, includes the service station power consumption rate, steam turbine heat rate, boiler efficiency, generator efficiency, potential transformer losses, and other parameters while the energy efficiency index at the macro level is centered on the fuel consumption required to produce power, including the consumption of coal and the service station power consumption rate. In addition, the National Bureau of Statistics in China periodically publishes data for the energy processing conversion efficiency of power generation and the power station supply industry in their China Energy Statistical Yearbooks.

Power production fuel consumption is also called power production standard fuel consumption and it mainly refers to the average standard fuel consumption that the thermal power plants use to produce one kilowatt-hour (kWh) of electricity, which is equal to the total electrical energy production divided by the total standard fuel consumption required to produce the electric power. Power supply coal consumption, also expressed as the coal equivalent consumption of the power supply, is the average coal equivalent consumption that the thermal power plants use to supply one kWh of electricity. It is a consumption indicator, which is calculated according to the ultimate capacity of the power plant, and it represents one of the most important national assessment targets for thermal power plants. The main difference between the power production fuel consumption and the power supply coal consumption is the power station's own electric power consumption, which includes the generators, lighting, heating and ventilation, and other control and protective devices (and excluding the electricity consumed by repair workshops, infrastructure and overhaul test runs, as well as refectories, dormitories, offices, roadway illumination, and so on). In general, the electricity volume of the internal power consumption, including the power consumed for office purposes, is considered "own demand." The power station's electricity consumption rate is the ratio of own demand to the total generation in the electricity production process.

The energy processing conversion efficiency is measured as the proportion of the amount of the various energy products and the amount of various input energy for processing and conversion after the energy is converted and processed within a certain period. It is an important index to observe whether the production technology is advanced and whether the regulation levels are high. Take the first megawatt ultra-supercritical domestic power station project—the Huaneng Yuhuan unit—as an example. The designed coal consumption is 272.9 g standard/kWh, and using 122.9 g standard/kWh as a conversion factor, its processing conversation efficiency is 45 %.

In researching the economics of electricity transmission, the power plant load rate is also an important index from which to measure the energy efficiency and it is associated with the hours of use of the power generation equipment. The load factor is the ratio of the average load to the maximum load in a specified time period, which is used to measure the changes in the load during a specified time period, as well as to determine the degree of use of the electrical equipment. The higher the equipment load time, the more efficient is the equipment use in terms of working hours. In general, the relation of the energy efficiency of the electrical equipment and load is a parabola. When the equipment operates at its rated value, the efficiency is at its highest. As a result, the load fluctuations of the energy demand determine that the load rate of the unit operations is of vital importance in the improvement of energy efficiency. The average number of hours of generation is the index to use when measuring the degree of use of the power plant's generation equipment; that is, it is the average number of hours that the plant operates at a set capacity under a full load in a given period. The formula of the load rate and average hours of use is as follows:

Average annual hours of equipment utilization = 365 days $*$ 24 h $*$ equipment availability rate $*$ generator's set annual load rate $*$ (1 − load emergency reserve rate).

In addition, the average equipment availability rate needs to be considered in two parts; the regular planned repair period and the temporary repair period. The number of hours of use of the generators is also an important index from which to measure the power supply and demand situation. The higher the use of the generation equipment, the higher is the efficiency. Nevertheless, overtopping means a lack of necessary standby capacity. As a result, it is necessary to have an appropriate average number of working hours for the equipment, so that the power network has ample standby capacity.

Table 5.14 shows China's energy efficiency index from 1955 to 2009. It is clear that the coal consumption used in the production and distribution of electric power, as well as the heat-engine plants' energy service power rate have all experienced a downward trend. The table also shows the use of the equipment to satisfy the supply and demand in different years.

Table 5.14 China's power industry energy efficiency index (1955–2009)

Index (unit)	Generating and power station heating efficiency (%)	Net coal consumption (gce/kwh)	Power produce coal consumption (gce/kwh)	Power consumption of power station			Hours of generating equipment use				Line loss rate
				Total (%)	Hydroelectric power (%)	Thermal power (%)	Total (hour)	Hydroelectric power (hour)	Thermal power (hour)	Nuclear power (hour)	(%)
1955	–	655	706	5.89	0.17	7.27	4510	5033	4377	–	
1960	–	553	600	7.12	0.13	7.85	5800	4415	6080	–	
1965	–	477	518	6.98	0.21	7.98	4920	3728	5217	–	7.31
1970	–	463	502	6.54	0.17	7.78	5526	3790	6100	–	9.22
1975	–	450	489	6.23	0.15	7.91	5197	4147	5631	–	10.13
1980	–	413	448	6.44	0.19	7.65	5078	3293	5775	–	8.93
1985	36.85	398	431	6.42	0.28	7.78	5308	3853	5893	–	8.18
1990	37.34	392	427	6.9	0.3	8.22	5041	3889	5417	–	8.06
1995	37.31	379	412	6.78	0.37	7.95	5121	3857	5454	–	8.77
2000	37.36	363	392	6.28	0.49	7.31	4517	3258	4848	–	7.70
2001	37.63	357	385	6.24	0.46	7.25	4588	3129	4900	–	7.55
2002	38.73	356	383	6.15	0.49	7.1	4860	3289	5272	–	7.45
2003	38.83	355	380	6.07	0.55	6.93	5245	3239	5676	–	7.53
2004	39.46	349	376	5.95	0.47	6.85	5455	3462	5991	–	7.57
2005	39.87	343	370	5.87	0.44	6.8	5425	3664	5865	7755	7.21
2006	39.87	334	366	6.15	0.46	6.77	5221	3434	5633	7774	7.08
2007	40.24	332	356	5.83	0.42	6.62	5011	3532	5316	7737	6.85
2008	–	322	345	5.89	0.35	6.81	4648	3589	4885	7829	6.79
2009	–	–	342	–	–	–	4527	3264	4839	7918	6.55

Notes Data from NBS-DE and NBE-DCS (2009), Editorial board of China Power Yearbook (2009), and CEC (2010). The electric power production sector mainly includes power plants above 6000 kw in its statistics

5.3.1.2 Energy Saving Management in the Electricity Generation Department

As presented above, the thermal power generation sector can improve its energy processing and conversion efficiencies mainly by decreasing the coal consumption per unit electric power production and decreasing the amount of the power stations' own consumption. The two major ways to realize these objectives are equipment optimization and load-rate improvement. The former includes improvements in the boiler, turbine, and alternator systems and a decrease in the amount of electric power produced by coal of their auxiliaries. At the same time, improving the operation of fans, water pumps, electrical transmission equipment, and so on will reduce the power stations' own electric power consumption rate (at present, the electricity consumption of the fan pumps represents 65–70 % of own consumption). The latter is dependent on modifying the operation of the electric power network and the construction of the power plants (including the plants' design).

The developed countries commonly adopt high-capacity and high-parameter thermal power generating units, whose power supply energy consumption and power stations' own electrical consumption rates are relatively low. Today, the average amount of coal consumption in supplying power from the internationally advanced heat-engine plants is about 320 g standard/kWh and the power stations' own consumption rate by including desulfurization devices is 4.5–5.5 %. Strongly promoting supercritical fluid technology is the main measure for reducing the amount of coal consumption in energy production at present. China can benefit from the design and manufacturing technology of supercritical and ultra-supercritical large generator units by introducing the technology and facilitating cooperation among regions in a short time; thus supporting the localization processes. After introducing, incorporating, and improving the technology in the generation process for a long time, as well as such initiatives as "putting great emphasis on small ideas" during the "ten-five" and "eleven-five" plans, the domestic thermal power unit structure has been optimized quite well, and the corresponding energy efficiencies have shown a sharp rise. Of the 9068 million kW of new thermal power installations in 2007, plants of 600 MW and above totaled 5300 million kW, accounting for 58 % of the total; thus, a pattern of large generation units with high capacities and high efficiencies has begun to appear in the electric power industry.

To improve the energy conversion efficiency, the priority in developing the thermal power technology in China includes SC, USC, CFB, IGCC, GTCC, CHP, CCHP, and so on. Table 5.15 (data is from the Editorial Board of Power Energy-Saving Technology Series 2008a) presents the advanced index of the national large and medium-sized fire motor. Today, the newly designed large units have production rates that are more or less equal to those in foreign countries in terms of thermal efficiency, power station own energy consumption, dust emissions, and the reliability index. The investments in the Zhejiang Yuhuan Huaneng power

Table 5.15 Advanced index of Chinese large- and medium-sized thermal power units

Pressure rating	Storage class MW	Energy supply coal consumption (gce/kWh)	Power consumption of power station (%)	Pressure rating	Storage class MW	Energy supply coal consumption (gce/kWh)	Power consumption of power station (%)
Supercritical unit	1000	285	3.31	Sub-critical unit	330	327	5.00
	600	305	3.34		300	334	5.01
	500	331	5.72		200	344	4.31
	300	326	4.82	Superhigh pressure unit	250	355	5.27
Subcritical unit	600	312	4.17		200	352	6.04
	350	313	4.46		125	350	6.54

plant in 2006 have resulted in the following performance tests: the unit energy supply was 283.2 g/kWh and the thermal efficiency of the power production system was 45.4 %, which compare to world-level performances.

5.3.2 Energy Efficiency of Power Transportation and Distribution

The electric energy that power stations generate is transported to terminal users (final demand) located hundreds or even thousands of kilometers away, via an interconnected power transmission and distribution network. Generally speaking, the conversion stations transport the electric energy to transformer stations near densely populated areas and the department whose working voltage is high is called the power transmission network. The distribution network is responsible for transporting the electric energy from the conversion stations to the terminal users. As its voltage class is comparatively low, it is not of much interest, in general. The transportation, transmission, and distribution equipment will produce energy losses through impedance, and the energy dissipates in the surrounding mediums in the form of heat. This energy loss is called power line loss or line loss for short. Line loss is a major part of the total energy loss in a power system. It not only improves the electric load but also results in an increase in the amount of extra electricity required in the system and thus a decrease in the energy efficiency. According to the statistical system in China, the power grid line loss is equal to the difference between the energy supply at the source and the energy sales volume (final demand) at the destination.

The ratio of the line loss in the power network to the energy supply is referred to as the line loss per unit. It is a comprehensive technology index of electric power enterprises that reflects their planning and design, technology and operation management levels of the electric power network, which is also influenced by the grid's topological structure, power position, electric energy production, power transmission and transformation equipment efficiency, user locations, load, and so on. From the early 1970s to late 1990s, the electric network line loss in China was always above 8.0 %, before turning downward as a whole. Two rural network reconstruction projects were subsequently started in 1998 and 2002, and they have made great improvements to the system. In 2009, the average line-loss rate in the country dropped to 6.72 %, where the line-loss rate of the State Grid Corporation of China, whose electric sales represented two-thirds of the total for the country, was 6.12 %. This rate is lower than that of the US, which was 6.27 % (EIA 2009). On the one hand, it reflects the advancements made in the technical equipment. On the other hand, it shows that the power-grid management and scheduling levels are improving. Even so, there is a long way to go before China catches up to world levels (the line-loss rate in Japan and Germany is below 5 %) and the line-loss rate in its rural districts and regions is much higher, which also means that the country can do better in terms of saving energy through its power grid. Calculated according to the 3.7 trillion kWh of electrical energy consumption in 2009, when the line loss rate falls by one percent, the energy demand will decrease 37 billion kWh, which equals 14 million tons of raw coal.

In terms of technology, the factors affecting the line-loss rate can be divided into line transformers and the distribution network. The reasons for higher line-loss rates include unreasonable power-grid planning, power sources located far from the load center or an overwide power supply radius resulting from an unreasonable network layout. Moreover, the network sections are too small or too large; the lines experience long-term light loads, no load at all or are overloaded, so that they do not operate at their peak state; line aging and material (porcelain) failures that cause the electricity leakages to increase; a shortage or excessive amount of stand-by electric power and so on. Similarly, the operation management may not be scientifically supported, and the main transformer equipment experiences overloaded or light-load operations, as well as reactive compensation shortages, equipment aging, and other reasons can also bring about the overtopping equipment losses at the substations. From the perspective of the distribution network, transformers far from the load center, capacity and load mismatching, unreasonable low voltage reactive compensation, three-phase load imbalances, and so on can also affect the degree of line losses.

To reduce the energy consumption of the electric power transmission network, it is basically necessary to improve the power grid construction and the upgrading of transformers and to have a reasonable operations mode in two ways. The former includes optimizing the power distribution, improving the network structure to power-boost the transformers, a more simplified voltage-grade level, replacing the substation and high-energy consumption equipment, adding value to the power supply, improving demand, applying new energy-saving technology related to equipment and materials, and so on. The latter includes mainly load optimizing allocations, adjusting the load curve, reasonable operating voltage levels and reactive power compensation, and transformer three-phase load balances to realize economically efficient operation of the electric power system. Relative to the power industry, the transmission network's energy efficiency factors are more complex and the space for energy savings is also bigger.

5.3.3 Electricity Allocation Optimization and Economical Transmission

Optimizing the allocation of resources and thereby strengthening the economic operations are important ways to improve the energy efficiency of the electric power industry. On the one hand, they can improve the utilization of water (hydro) to produce electricity and the use of other renewable energy resources. On the other hand, they can increase the unit load of the operation, reduce equipment non-productive and maintenance times, and improve the energy conversion efficiency.

5.3.3.1 Optimize the Power Supply Structure

Coal makes up the largest share of the energy structure in China and it is also one of the main characteristics of the electric power structure. Relative to the fast growth in oil demand, China's domestic oil production and future growth is limited, so its oil supply is inadequate. As a result, the country's foreign dependence for oil is increasing. To ensure national energy security, it is inadvisable to use oil and gas resources of high quality for power generation. While China is abundant in coal resources, there are disadvantages that are difficult to overcome, such as the issue of carbon dioxide emissions. China's energy development strategy includes the pursuit of not only a supply and demand balance but also a diversified energy structure (including "green" types of energy) and a sustainable development model. Development and the use of renewable energy is one of the main objectives of China's energy strategy, as it is considered to be the best way to achieve the country's goals.

China includes 9.6 million square kilometers of land and more than 300 million square kilometers of ocean, where renewable resources are abundant. According to the latest review of water resources, the country's power output (in theory) is 6.0829 trillion kWh, with an average installed capacity of 694.4 million kW. The installed capacity that can be developed using the existing technologies is 521.64 million kW, with a generating capacity of 2.474 trillion kWh. The evaluation of wind energy resources shows that the available capacity in the country is 300 million kW and including near-shore waters, it amounts to one billion kW. Two-thirds of country's land area experiences annual sunshine rates greater than 2200 h, and the total solar radiation is greater than 50 mega joules per square meter in those areas with the best conditions for solar energy.

In 2009, China's hydropower installed capacity was 196 million kW, ranking first in the world, but the development rate was less than 30 %, so there is still much room for future development. At the end of 2009, the total installed capacity of wind power was 17.6 million kW, ranking third in the world and surpassing the country's nuclear power installed capacity. In 2010, China's wind power is expected to surpass that in Europe and the US. China will then have the world's largest installed capacity, reaching 30 million kW, and the country will have achieved its planning objectives well ahead of 2020. In 2009, China's solar energy capacity was about 25,000 kW, but the output has ranked first in the world with 2.4 million kW.

After years of rapid development, China's renewable energy power generation technology has improved and its major equipment production capacity and total production have leaped into the front rankings of the world, which means that the country has a good foundation for further development. Accelerating the development of renewable energy will greatly enhance the efficiency of energy use in China and play both alternative and complementary roles to fossil fuels.

5.3.3.2 Promote Power Grid Construction

To achieve the full development and utilization of renewable energy, we must strengthen the planning and construction of the power grid. Our regional energy supply and demand imbalance is a great contradiction, as the energy consumption is mainly concentrated in the economically more developed eastern part of the country, including the Bohai Bay, Yangtze River Delta, and Pearl River Delta regions; the energy resources are mainly located in the western and northern areas of the country. Take water and electricity as an example. China's 13 provinces and cities in the eastern part of the country (Heilongjiang, Jilin, Liaoning, Beijing, Tianjin, Hubei, Shandong, Jiangsu, Zhejiang, Shanghai, Guangdong, Fujian, Hainan) account for only 8 % of the total water resources while the 11 provinces in the western part of the country (Yunnan, Fuzhou, Sichuan, Chongqing, Shaanxi, Gansu, Ningxia, Xinxiang, Tibet, Guilin, Mongolia) account for up to 81 %. Solar and wind power generation are also facing the same predicament. The most abundant areas of solar energy resources in China include Ningxia, Gansu, Xinjiang, and Qinghai. The land-based wind energy resources are mainly concentrated in northern Xinjiang, Inner Mongolia, Gansu Province in northern Heilongjiang, eastern Jilin, northern Hubei, and the Liaodong peninsula, which are far from the main electricity markets. Electric power engineering projects, such as the Three Gorges Dam project, is a main way to balance China's regional energy shortages. Connecting the energy-rich western regions and their power stations with the eastern regions, where there are energy shortages, not only takes full advantage of the resources located in the west but also improves the overall differences in inter-regional power generation by coordinating the advantages and disadvantages of the various regional resources.

As China's most important type of energy, coal also shows a serious imbalance in terms of regional supply and demand (Fig. 5.22). The data is from the NBS-DE and NBE-DCS (2009). Northern Shanxi, Inner Mongolia, and Shaanxi provinces are major coal exporters while the demand is concentrated in the eastern coastal provinces of Shandong, Jiangsu, Guangdong, Hubei, and other areas. Long-distance and large-scale inter-regional coal transportation will inevitably lead to greater energy losses. In terms of the efficiency of land transport for the best railway system in 2008, the energy consumed by electric locomotive per ten thousand ton and kilometer was 110.6 kilowatt-hours, and that of Diesel Locomotives was 24.9 kg. Converted into coal consumption, the energy consumption to convey 10,000 tons of coals for 1000 km are 3.7 and 5.1 %, respectively plus 0.8–1 % loss rate, which does not have the advantage compared with transmission power.

In addition, China's railway construction program is seriously lagging behind in terms of economic and social development, having completed only 25 % of the task for a total network mileage of less than 6 % of the world's total, where there are long-term high-load conditions and a serious shortage of capacity. Coal accounts for nearly half of China's total railway freight volume, but in many parts of the country, the proportion is less than 30 %. Rail transportation has become the main

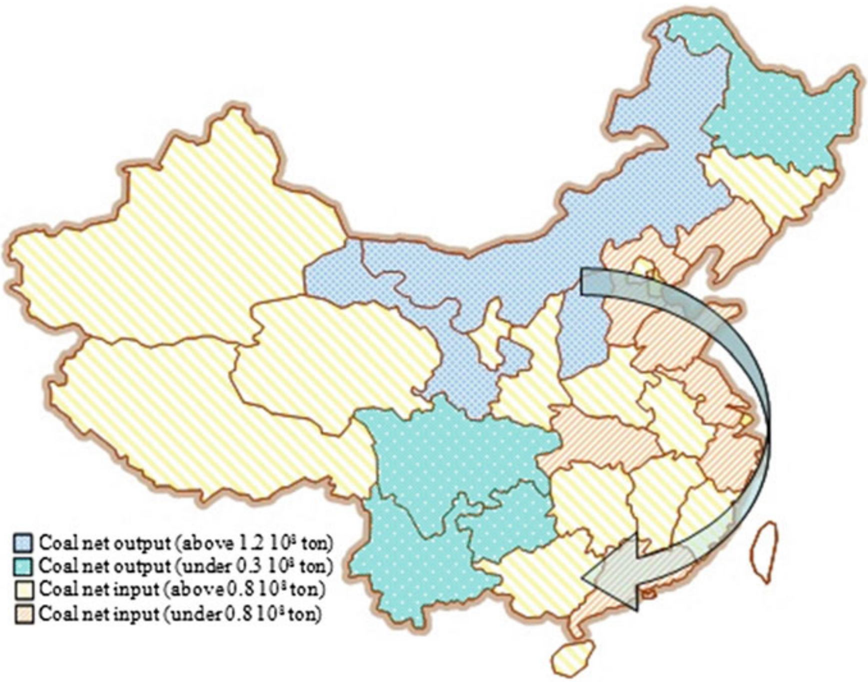

Fig. 5.22 Comparison of China's regional coal supply and demand situation. The figure shows a schematic diagram, which does not represent the administrative divisions or boundaries

bottleneck restricting the coal supply and it also affects the transport of other materials. In addition, natural monopolies and individual deployment systems within the railway network mean that each region only considers its own situation. Considering the lack of adequate communication and coordination between regions, it is necessary to attempt to complement the "electricity transmission" system as an effective "coal-based transmission" system. In addition, in terms of the exploitation and investment in land resources, operating costs, safety and environmental protection, an electric grid has better characteristics than the transport of coal.

5.3.3.3 Improve the Load Rate

The load rate is an important technical and economic indicator that reflects the power generation, power supply, and electrical equipment and whether one is taking full advantage of the electrical system. It equals the ratio of the average electricity load to the maximum electricity load. When considering the economic and operational aspects, one needs to determine if the load rate is close to 100 %

and if there is sufficient spare capacity in the system and for the operating equipment.

A load rate rise of 10 % will enable the line loss rate to be reduced by 2 % (Editorial Board of Power Energy-Saving Technology Series 2008b) and the energy-savings from a more economic distribution of electricity is obvious, so large-scale inter-regional power grid interconnections are the precondition to achieving these goals. For the power generation equipment, high loads are a necessary way to ensure energy efficiency (for example, the Yuhuan 1000 MW ultra-supercritical units). When the operating load rate drops to 60 % of the rated load, the heat consumption rate will be lower than the heat rate of the supercritical 600 MW units under rated operating conditions. When the operating load rate is less than 40 % of the rated load, the heat consumption rate will be lower than the heat rate of 300 MW units under rated operating conditions (Zhang et al. 2007).

Generation load improves the hydro, wind, and other renewable energy generation utilization rates mainly through scientific innovations and controls. Most parts of China are located in the northern temperate zone, which has a mild climate with four distinct seasons, as well as a continental monsoon season. There is a large precipitation and river-runoff gap between the wet and dry seasons. Hydropower during the wet season is mainly responsible for the base load and lumbar load while during the dry season, it is mainly committed to the peak load. There are similar problems in wind and solar energy and the generation of other renewable energies. Reasonable optimal scheduling of the regional power grid interconnections can not only be complementary, thereby increasing renewable energy use efficiency and saving fossil fuels, it can also have cross-river system hydrology compensation benefits between upstream and downstream power plant capacities. In addition, the rate of increase of the power generation load will effectively reduce the standby load, thereby reducing the power generation's installed capacity and saving power investments.

Raising the rate of electricity loads mainly through inter-regional networks and demand-side management is central to the proper distribution and use of electricity. China has a vast territory, situated across more than 60° of longitude between east and west and between nearly 50° of latitude between north and south. After interconnecting the eastern and western grids, it is possible to increase the effectiveness of peak shifting according to the differences in daily inter-regional peak demand and to increase the generation set load rates and thereby reduce coal consumption and the corresponding line losses. The north–south grid interconnection can also gain from seasonal peak-shifting efficiencies, which reduce the annual maximum load; thereby, saving further investments and reducing the costs.

5.3.4 Demand Side Management and Energy Efficiency

This section starts from the two aspects of power generation and transmission and distribution from the economic and technical points of view; throws light on the power industry measurement of energy efficiency indicators and methods and simulates the energy efficiency for the objective function of power load management. The power industry requires a great amount of capital and it is a technology-intensive industry, in which the production of electricity is a complicated process that requires a huge amount of energy consumption. However, it has a great potential and many ways to improve its efficiency. The energy efficiency of the entire power system must not only consider both supply and demand factors, it must establish an appropriate pricing mechanism to achieve an effective allocation of resources, and it should speed up its technological progress and promote the diversification of new power sources, as well as renewable energy standards, to achieve long-term sustainable development.

5.4 Summary

Transportation, construction, and electricity are the key sectors of the current and future energy consumption in China. This chapter focused on China's transportation sector, public construction sector, and electricity sector.

(1) China's transportation energy consumption is mostly petroleum products, in which oil accounted for up to 86.2 % in 2007. Transportation, especially road transport's total energy consumption, has grown rapidly. The transportation units' converted turnover overall energy consumption has declined while the unit value added of energy consumption has experienced an upward trend. Apart from road transport, the energy intensity of waterways, railways, civil aviation, and other modes of transport has experienced a greater degree of decline.

(2) In China's public buildings, electric power consumption has dominated this subsector's energy consumption structure and its status has enhanced the overall trend toward more electricity consumption. According to the China Statistical Yearbooks from 1996 to 2006, the proportion of electricity consumption in public buildings has increased from 52 to 66 %. Specifically, public building electricity consumption increased from 92.4 billion kWh in 1996 to 281.3 billion kWh in 2006, accounting for 45–50 % of the total power consumption of buildings. The architectural design and characteristics of the large public buildings, as well as their energy-use differences, are the main reasons for the huge energy consumption. China's regional public building energy consumption levels show significant imbalances and the provinces with the highest public building energy consumption are mainly located in the eastern coastal areas.

The power industry requires a great amount of capital and it is a technology-intensive industry. Its production and transportation processes are cumbersome and complex, and its energy consumption is huge, but the power industry also has a great potential and many ways to improve its efficiency. The energy efficiency of the entire power system must not only rely on both supply and demand factors, it must also rely on an appropriate pricing mechanism to achieve an effective allocation of resources. Furthermore, the electric power system must speed up its technological progress and level of multi-Ha its use of renewable sources in order to realize long-term sustainable development.

References

Cai FT, Liu L, Han LB (2006) Road transport energy consumption status and energy saving measures. Transp Energy Conserv Environ Prot (3)

China Communications Yearbook Press (2000a) Yearbook of China transportation and communications 2000. China Transportation Yearbook Press, Beijing

China Communications Yearbook Press (2000b) Yearbook of China transportation and communications (Essence) 1986–2000. China Transportation Yearbook Press, Beijing

China Communications Yearbook Press (2001) Yearbook of China transportation and communications 2001. China Transportation Yearbook Press, Beijing

China Communications Yearbook Press (2002) Yearbook of China transportation and communications 2002. China Transportation Yearbook Press, Beijing

China Communications Yearbook Press (2003) Yearbook of China transportation and communications 2003. China Transportation Yearbook Press, Beijing

China Communications Yearbook Press (2004) Yearbook of China transportation and communications 2004. China Transportation Yearbook Press, Beijing

China Communications Yearbook Press (2005) Yearbook of China transportation and communications 2005. China Transportation Yearbook Press, Beijing

China Communications Yearbook Press (2006) Yearbook of China transportation and communications 2006. China Transportation Yearbook Press, Beijing

China Communications Yearbook Press (2007) Yearbook of China transportation and communications 2007. China Transportation Yearbook Press, Beijing

China Communications Yearbook Press (2008) Yearbook of China transportation and communications 2008. China Transportation Yearbook Press, Beijing

China Communications Yearbook Press (2009) Yearbook of China transportation and communications 2009. China Transportation Yearbook Press, Beijing

China Electricity Council (2010) National Power Industry Statistics Bulletin 2009

China Energy and Carbon Emissions Research Team (2009) 2050 China energy and carbon emissions report. Science Press, Beijing

Comprehensive Transportation Research Institute of National Development and Reform Commission (2007) Economical transportation development mode. Comprehensive Transportation Research Institute of National Development and Reform Commission, Beijing

Department of Comprehensive Planning of the Ministry of Transport (2008) A Long-term Plan for Highway, Waterway Transportation Energy Conservation (Jiao Gui Hua Fa [2008] no. 331)

Department of Comprehensive Planning of the Ministry of Transport (2009) Study on energy-saving medium- and long-term planning in transportation industry

Department of Energy of National Bureau of Statistics, Department of Comprehensive Statistics of National Energy Administration (2010) China energy statistical yearbook 2009. China Statistics Press, Beijing

Department of Industry and Transport Statistics of National Bureau of Statistics (1990) China energy statistical yearbook 1989. China Statistics Press, Beijing

Department of Industry and Transport Statistics of National Bureau of Statistics (1998) China energy statistical yearbook 1991–1996. China Statistics Press, Beijing

Department of Industry and Transport Statistics of National Bureau of Statistics (2001) China energy statistical yearbook 1997–1999. China Statistics Press, Beijing

Department of Industry and Transport Statistics of National Bureau of Statistics, Bureau of Energy of National Development and Reform Commission (2003) China energy statistical yearbook 2000–2002. China Statistics Press, Beijing

Department of Planning and Development, Civil Aviation Administration of China (2008) Statistical data on civil aviation of China 2007. China Civil Aviation Press, Beijing

Department of Planning and Development, Civil Aviation Administration of China (2009) Statistical data on civil aviation of China 2008. China Civil Aviation Press, Beijing

Editorial Board of China Power Yearbook (2009) China electric power yearbook 2009. China Electric Power Press, Beijing

Editorial Board of Power Energy-Saving Technology Series (2008a) Power energy saving policy and management. China Electric Power Press, Beijing

Editorial Board of Power Energy-Saving Technology Series (2008b) Power transmission and transformation system energy saving technology. China Electric Power Press, Beijing

EIA (2009) Electric power annual 2007. Energy information administration (EIA), Department of Energy, US

Energy Research Institute of National Development and Reform Commission, Research Center for Building Energy Conservation, Tsinghua University (2009) Study on China's large public building energy saving management. Energy Research Institute of National Development and Reform Commission, Beijing

Eurostat (2009) Eurostat Database. European Commission

Fridley D, Aden N (2008) China energy databook (version 7.0). Lawrence Berkeley National Laboratory (LBNL), Berkeley

Gordon D (2005) Summarization of international experience of fiscal and taxation policies to promote the sustainable development of transportation

Han QD (2009) Speech in the summit forum of low carbon economy and green building industry development

IEA (2009) CO_2 emissions from fuel combustion: highlights (2009 edition). International Energy Agency (IEA), Paris

IEEJ (2007) Handbook of energy and economic statistics in Japan. The Energy Conservation Center, Tokyo

IEEJ (2008) Handbook of energy and economic statistics in Japan. The Energy Conservation Center, Tokyo

Japan's Energy Conservation Center (2008) Japanese energy-saving manual 2008 (in Japanese). Japanese Energy Conservation Center, Tokyo

National Bureau of Statistics (1987) China statistical yearbook 1987. China Statistics Press, Beijing

National Bureau of Statistics (2005) China statistical yearbook 2005. China Statistics Press, Beijing

National Bureau of Statistics (2007a) China statistical yearbook 2006. China Statistics Press, Beijing

National Bureau of Statistics (2007b) China statistical yearbook 2007. China Statistics Press, Beijing

National Bureau of Statistics (2008) China statistical yearbook 2008. China Statistics Press, Beijing

National Bureau of Statistics (2009) China statistical yearbook 2009. China Statistics Press, Beijing

National Bureau of Statistics (2010) National economic and social development statistical bulletin in 2009 of China. China Statistics Press, Beijing

National Development and Reform Commission (2004) Long-term energy saving special planning (Fa Gai Huan Zi [2004] no. 2505)

ODYSSEE (2009) Odyssee Database

ORNL (2009) Transportation energy data book (edition 28). Oak Ridge National Laboratory (ORNL), Cherahala Boulevard

Research Center for Building Energy Conservation, Tsinghua University (2008) Annual report of China's building energy conservation development 2008. China Building Industry Press, Beijing

Statistics Center of Ministry of Railway (2008) National railway statistics yearbook 2006. China Railway Press, Beijing

Statistics Center of Ministry of Railway (2009a) National railway statistics yearbook 2006. China Railway Press, Beijing

Statistics Center of Ministry of Railway (2009b) Concise information about railway statistic. China Railway Press, Beijing

Team of Energy Research Institute of National Development and Reform Commission (2009) China's low carbon development path in 2050–energy demand (carbon emissions scenario) analysis. Science Press, Beijing

Wang QY (2008) Financial and economic policy research resources of sustainable energy development: energy data in 2008. Financial and Economic Policy Research Resources of Sustainable Energy Development, China Sustainable Energy Projects

Zhang SY (2006) Energy saving on transportation emphasizes structure adjustment–interview with national development and reform commission comprehensive transportation researcher Yang Hongnian. China Econ Rev

Zhang YF, Zhu BT, Lei ZT (2007) Study on load under economic operation of ultra-supercritical units. Therm Power Gener 22(11):1–3

Chapter 6
Empirical Research About the Effects of Price on Oil Demand

In recent years, along with the rapid development of the Chinese economy, the international oil price has climbed substantially. The demand for oil reached a record high, so that a common refrain was "the higher the price of oil, the greater the demand of oil." There was even the belief that the rise in oil prices had no impact on energy savings. There are many factors affecting oil demand, such as economic development and, in particular, oil prices. Therefore, it is especially important to research the effects of the oil price on oil demand in terms of scientifically understanding the functions of the price mechanisms and the effects of changing prices on energy savings. This chapter focuses on questions of crude oil demand and price, and our research emphasizes the influence of price on crude oil demand, the demand driving the level of economic activities, and the substitution effects of coal. We seek to answer the following questions:

- To what degree does crude oil demand influence the price elasticity?
- How do economic activities affect oil demand?
- Can coal take the place of oil demand in China or how can coal replace oil?

6.1 Introduction

Oil is an important fossil energy that is involved at all levels of society's socioeconomic structure and it plays an increasingly significant role in our national economy and social livelihood. In China, the production of oil can no longer satisfy the requirements of economic development. External dependence on oil reached 50 % in 2008. A rapid increase in oil consumption was once regarded as a major factor that caused oil prices to rise. As a result, it is obvious that a study of the driving factors of Chinese oil consumption is extremely important and that it is profoundly necessary to reduce oil consumption.

Y.-M. Wei and H. Liao, *Energy Economics: Energy Efficiency in China*,
DOI 10.1007/978-3-319-44631-8_6

Oil price is the main factor that influences oil consumption and production. We cannot ignore the fact that a rise in oil prices reflects a supply shortage in the markets for crude oil and refined oil products, along with an increasing demand for oil. According to research by the IEA (2006), the OECD members will need to import two-thirds of their total oil demand by 2030, from 50 % today. It is no doubt that the rapid increase in oil demand will lead to a relatively slow response in terms of the oil price and that the demand of transportation will take up a rising share of the total oil consumption. However, compared with other energy-consumption sectors, there is essentially no elasticity between the transportation demand and oil prices, so the response of oil demand to international crude oil price variations is becoming slower and smaller. At the same time, rising demand and changes in the costs of production will affect the oil price directly, and people generally believe that oil prices will rise in the future; that is, \$87/barrel in 2015 and \$115/barrel in 2030. It is also believed that the marginal cost of supplies will increase and that the oil demand of non-OECD members will also rise, which will influence the oil price and cause it to rise. Therefore, the oil price and the oil demand affect each other, and the price elasticity influences the oil demand. Further, the research on price elasticity becomes more significant. There are many scholars who have done such quantitative research. Bentzen and Engsted (1993) analyzed the effects of energy prices and GDP on energy demand by taking advantage of a cointegration model. Sandbach (1998) analyzed the price sensitivity of gas and fuel oil while Ramcharran (2002) analyzed the influence of oil prices on oil production in the OPEC and non-OPEC countries. Krichene (2005) used simultaneous equations to study the price elasticity of the oil and gas markets worldwide. At present, China is still in an inferior position to study oil demand price elasticity. Cooper (2003) analyzed the annual data in China from 1979 to 2000 and concluded that the long-term crude oil demand elasticity was 0.005 (algebraic value, the same below) while the short-term elasticity was 0.001, which greatly lacked any elasticity due to non-significance.

We believe that oil price changes in the year, including the processes of change, are bound to affect the demand for crude oil and that using the monthly price of crude oil may be more appropriate in calculating the price elasticity of oil demand in China. Crude oil is the energy source that is the pillar of economic development, so uneven economic development will greatly affect the demand for crude oil. At the same time, international political factors, as well as international speculators and investment funds, will exacerbate the variation in oil prices throughout a given year. According to EIA statistics, the monthly average price of Brent crude oil in 2008 was \$96.85/barrel, where the highest price was \$132.72/barrel and the lowest price was \$39.95/barrel, or a spread of \$92.77/barrel. Thus, using annual data to calculate the elasticity of demand for crude oil will lead to considerable error. On the other hand, China's coal energy represented a large proportion of the energy supply (68.7 % in 2008), so it is very important to estimate the alternative price elasticity of coal to crude oil. Moreover, coal is affected by seasonal effects (e.g., winter heating in northern China is mainly by coal). Therefore, it is necessary to use monthly data to calculate the elasticity of the substitution of coal for crude oil.

Oil demand can be influenced by industrial production and a hysteresis phenomenon exists whereby increasing production brings about a rise in oil demand. On the other hand, the oil demand can also be influenced by the price of other types of products. As stated earlier, China's dependence on foreign oil is more than 50 %. Changes in oil prices affect crude oil imports and there is the same hysteresis, as with production. All of these proxy variables include a hysteresis function on oil demand and, at the same time, the last sale of crude oil will influence the next. Johansen and Juselius (1990) used a cointegration VAR and we could possibly use this approach to analyze the relationship between the oil price and its influencing factors. However, all variables are single integrals, which involve the option between endogenous and exogenous variables, and determine the lag level. Therefore, the factors cause a comparatively large uncertainty and they make the robustness of the model low (Pesaran et al. 2001). So, in this chapter, we choose bounds testing and the Autoregressive Distributed Lag Approach (ARDL) model. Bounds testing can help to study whether there is a long-term relationship among the variables and the ARDL model can be used to study these long-term equilibrium relationships, which are related to the autoregression and lag, and can be applied to I (0), I (1) or a mix of I (0), I (1). Another advantage of bounds testing is that, when the variable is found to be endogenous, it does not influence the model estimations.

6.2 Research Method on the Demand Elasticity of China's Crude Oil

6.2.1 Variable Selections and Research Methods

The demand for crude oil is influenced by many factors. From our perspective, industrial production accounts for most of the demand and the use of GDP is the preferred income variable. However, no GDP monthly data is currently available for China and, as mentioned above, using monthly data is better for determining the crude oil demand price elasticity. Hence, we use monthly industrial gross output to represent variations in income and crude oil demand because industry is one of the main oil-consuming sectors and it represents most of the crude oil demand. Moreover, the inventory of crude oil and the industrial production process can influence oil demand as well, so we use the industrial products price index (PPI), which measures the changes in the prices of various commodities at different stages of production. Other factors, like weather, can also affect oil demand. During cold weather, people need heat, so there is an increase in oil demand. Therefore, the monthly demand for crude oil includes a monthly adjustment to account for cyclical factors such as seasonal changes that affect the computation of the actual crude oil demand price elasticity.

China's energy structure mainly consists of coal and oil. In 2009, coal represented 70.3 % of the total energy consumption while oil was 18.0 %. The elasticity of the substitution of coal for crude oil is most important. Replacement elasticity is the effect of a rise in coal prices on crude oil demand. By researching the replacement elasticity, we can determine the ability of coal to replace crude oil under present conditions in China. Given that this substitution is very small and that crude oil demand seems to lack any elasticity, we will not need thousands of tons of coal to replace crude oil when the price of oil goes up.

According to the above, we adopt the total industry output value and coal price as proxy variables to compute the crude oil demand elasticity. We use the Autoregressive Distributed Lag Approach (ADLA) by Pesaran and Pesaran (1997) and Pesaran et al. (2001), and bounds testing to determine if a long-term stable relationship exists between the variables; that is, whether there is a cointegration relationship. If it does, then we can estimate the long-term correlation coefficient.

According to the analysis, we can establish the following model:

$$\begin{aligned}\Delta \ln D_t = c + \sum_{i=1}^{p-1} \alpha_i \Delta \ln D_{t-i} + \sum_{i=0}^{p-1} \beta_i \Delta \ln Y_{t-i} + \sum_{i=0}^{p-1} \gamma_i \Delta \ln P_{t-i} + \sum_{i=0}^{p-1} \varphi_i \Delta \ln C_{t-j} \\ + \delta_1 \ln D_{t-1} + \delta_2 \ln Y_{t-1} + \delta_3 \ln P_{t-1} + \delta_4 \ln C_{t-1} + \varepsilon_t\end{aligned} \tag{6.1}$$

where D_t stands for crude oil demand, c is a constant term, Y_t is the total gross industrial output value, P_t stands for the crude oil price, C_t is the coal price, ε_t, is the disturbance, and α, β, r, φ, $\theta_{1,}$ $\theta_{2,}$ $\theta_{3,}$ are the coefficients and p is the lag order.

The null hypothesis verifies that, if there is a cointegration relationship on the effect of the gross industrial output value, then the crude oil price and coal price are not based on a stable long-term relationship:

Null hypothesis H_0: $\delta_1 = \delta_2 = \delta_3 = \delta_4 = 0$
Alternative hypothesis H_1: $\delta_1 \neq 0$ or $\delta_2 \neq 0$, or $\delta_3 \neq 0$, or $\delta_4 \neq 0$

Inspect According to the F-test, if the result is greater than the marginal value, then the null hypothesis that no cointegration relationship exists will be refuted and the alternative hypothesis that this kind of relationship exists will be accepted. If the result is smaller than the critical value, then we accept the null hypothesis; but if the F-value is between these two values, it will be difficult to judge one way or another. If the cointegration relationship is accepted, then we can compute the long-term dynamic coefficients for D, Y, P and C, using Eq. 6.1 and ARDL (p_1, $p_{2,}$ $p_{3,}$ p_4). According to the Schwarz Bayesian Criterion (SBC) formula, which is used to choose the best lag order:

$$\ln D_t = c + \sum_{i=1}^{p_1} \mu_i \ln D_{t-i} + \sum_{j=0}^{p_2} v_j \ln Y_{t-j} + \sum_{k=0}^{p_3} \tau_i \ln P_{t-k} + \sum_{s=0}^{p_4} \upsilon_i \ln C_{t-s} + \varepsilon_t \tag{6.2}$$

According to Eqs. 6.1 and 6.2, we can compute the ARDL-ECM short-term impact coefficient and the long-term coefficient, respectively.

6.2.2 Data Sources and Processing

On the basis of the aforementioned analysis, this chapter will study the crude oil demand price elasticity and the substitution effect of coal. The variables and data are as follows:

(1) Oil demand. Taking the availability of monthly data into consideration, we mainly use the changes in crude oil demand and prices to analyze the demand elasticity of price. Chinese monthly data about crude oil demand adopts the following computational procedure: volume of crude oil = crude oil production + oil imports − oil exports − incremental inventories. We modify X126.1[1] in terms of oil demand based on monthly data to eliminate seasonal factors. All data about the volume of oil production, oil imports, exports and incremental inventories from January 2002 to July 2009 come from the International Energy BBS database.
(2) Gross industrial output value. Because of the caliber of the data, the constant total gross industrial output value can be computed as follows: total gross industrial output value = original data about total gross industrial output value/industrial products price index (PPI). This measure also uses X12 to make seasonal adjustments. All the original data from January 2002 to July 2009 come from the Wind database.
(3) Crude oil price. Here, we mainly study the price elasticity of Chinese oil demand, so we adopt weekly data from the Daqing oil products price and turn them into monthly data, using the adjustments of the exchange rate between the USD to RMB currencies to adjust the price. The data from Daqing are found on the EIA website and the exchange rates are from the website of the People's Bank of China (from January 2002 to July 2009).
(4) Coal price. The coal price adopts the average price of coking clean coal in 36 major cities in China, which comes from the Wind database (from January 2001 to July 2009).
(5) PPI. PPI takes advantage of the data from month to month and converts the data on the basis of January 2002, which comes from Wind database (from January 2002 to July 2009).

[1]X12 is developed on the basis of X11 in the U.S. Census Bureau, in which all data have adopted X12 to make the adjustments. As for the computation of X12 monthly data, please see http://www.census.gov/srd/www/x12a/.

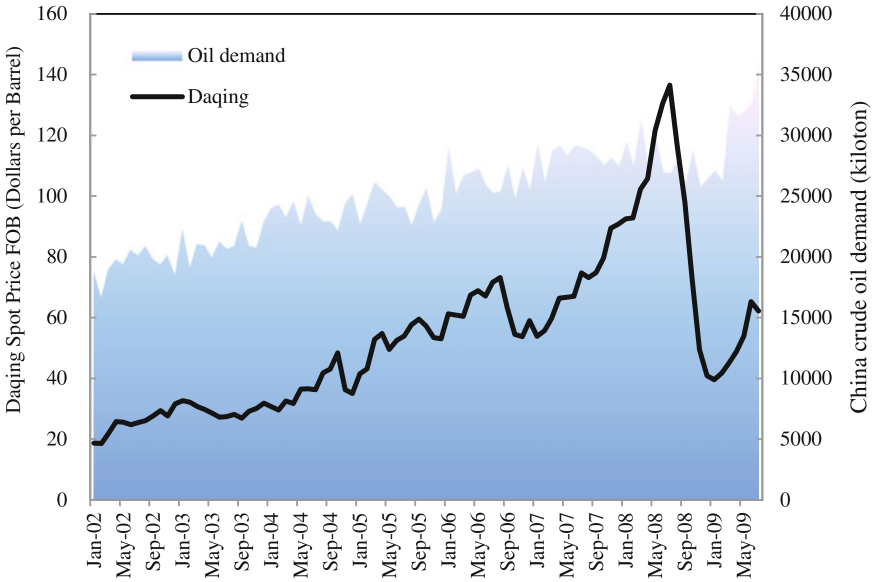

Fig. 6.1 Chinese oil demand and the oil cash price (2002–2009). Seasonal adjustments are not made

To make comparative analyses, the proxy variables of income use the monthly data of industrial growth adjusted by PPI and X12, using the Wind database (from 2001 to July 2009).

After analysis of the relationships among oil demand, gross industrial output values, oil prices and coal prices, and in order to study the influence of PPI on the demand elasticity, we compare these relationships only after we have made the PPI adjustments for the oil and coal prices (Fig. 6.1).

6.2.3 Data Analysis and Bounds Test

ARDL has many advantages, except that all variables should be I (1); therefore, we should conduct a unit root test to determine whether all variables are stable. The results are presented in Table 6.1. From the table, all variables are I (1), and are, therefore, desirable.

From the test results (Table 6.1), crude oil demand (less than 5 %) in terms of trend and time, is comparatively stable and the coal price (5 %) is stable, showing that the added time trends and constant terms for the oil demand and coal price are stable to some extent. The gross industrial output value and oil price do not satisfy I (0), but they do satisfy I (1).

Table 6.1 The results of the unit root test

	n	c	ct	n	c	ct
	Level			First different		
ln *D*	2.4703 (0.9966)	−0.9868 (0.7551)	−3.8811 (0.0168)	−9.8097 (0.0000)	−10.4001 (0.0000)	−10.3255 (0.0000)
ln *Y*	6.0433 (1.0000)	−1.1258 (0.7026)	−2.1322 (0.5207)	−0.7339 (0.3955)	−10.7050 (0.0000)	−10.7343 (0.0000)
ln *P*	0.5265 (0.8277)	−2.4455 (0.1325)	−2.5570 (0.3008)	−6.3396 (0.0000)	−6.3589 (0.0002)	−6.4436 (0.0007)
ln *C*	1.8790 (0.9852)	−0.7246 (0.8344)	−3.6097 (0.0347)	−6.1872 (0.0000)	−6.5708 (0.0000)	−6.5328 (0.0000)

n, c, ct stand for no constant term and time-trend term, constant term, and constant term and time-trend term, respectively. Significance is shown in brackets. The lag length is in accordance with AIC

According to Eq. 6.1, we select the longest lag period of the differential variations, whose value is 7; namely, p = 8, to conduct the bounds test. The results can be seen in Table 6.2

Panel A: oil demand, gross industrial output value, oil price, coal price

Panel B: oil demand, gross industrial output value, oil price (PPI adjustment), coal price (PPI adjustment)

There is a long-term cointegration relationship among oil demand, gross industrial output values, oil prices, and coal prices. From Table 6.2, we can see that at the 1 % significance level, all of the equations' F-values are significant in the lag 5 situation (trend term). And oil demand, gross industrial output values, oil prices (after adjustments by PPI) and coal prices (after adjustments by PPI) are also significant in the lag 5 situation, and there exist outstanding long-term relationships. From our analysis based on general economic principles, an increase in the gross industrial output value must require an increase in oil demand because industrial development drives the rise in oil consumption; the oil price clearly affects oil demand as total consumption decreases with a rise in price; coal, as substitute of oil, can influence oil demand whenever there are fluctuations in the coal price. If coal substitution is a large-enough option, then as coal prices rise, oil demand will increase.

Table 6.2 Bounds test results

	1	2	3	4	5	6	7	8
Panel A: crude oil demand, total industry output, crude oil price, coal price								
F_{μ}	0.6829	3.6562*	5.4567***	4.0462*	3.2089*	1.7905	1.4784	1.5588
F_{τ}	15.5896***	5.3501***	6.7367***	4.9738***	3.9722**	2.5794	1.7121	1.3955
Panel B: Crude oil demand, total industry output, crude oil price (PPP adjusted), coal price (PPP adjusted)								
F_{μ}	0.5547	3.3850*	4.9499**	3.9478**	4.2362**	1.9626	1.6127	1.5511
F_{τ}	11.6689***	4.7907**	6.0421***	4.8625**	4.5859**	2.9221	2.0030	1.5731

F_u and F_r stand for no trend term and trend term, respectively. For the marginal values, refer to Pesaran (2001): Table CI (i), Table CI (iii). *, **, *** represent the original hypothesis that refuses the no cointegration relationships between level variables at the 10, 5, and 1 % significance levels

6.3 Analysis of the Demand Elasticity of China's Crude Oil

6.3.1 Analysis of Crude Oil Demand Elasticity in the Long Run

According to bounds testing, there is a long-term cointegration relationship among oil demand, gross industrial output values, oil prices, and coal prices. We can form relationships among these variables on the basis of Eq. (6.2) and make some adjustments on oil and coal prices, using PPI. The estimations are shown in Table 6.3.

According to the equation, the sign of the variables are in accordance with our fundamental expectations. Industrial production will lead to an increase in oil consumption while a rise in oil price will bring about a decrease in oil demand. From the view of elasticity, where a unit change in the explanatory variable will lead to a change in the dependent variables, the degree of influence is smaller than that for industrial production.

In the long term, there is a negative relationship between the oil price and oil demand. A 1 % rise in price will cause a decrease in oil demand of 0.2113 %; and if the real oil price goes up by 1 %, then the oil demand will fall by 3.8598 t. The effect of the long-term elasticity of price on oil demand is less than unity, revealing that price lacks elasticity in the oil market in China. However, the industrial elasticity is relatively large—a 1 % rise in the gross industrial output value will cause a 0.5128 % increase in oil demand. In China, the industrial oil demand elasticity is much greater than the price elasticity of oil demand.

Table 6.3 The long-term price elasticity of oil in China

Parameter	(6.1)		(6.2)	
	Coefficient	T statistics	Coefficient	T statistics
ln *Y*	0.5128	3.6910 (0.000)	0.4742	3.6955 (0.000)
ln *P*	−0.2113	−1.7250 (0.089)	−0.2284	−1.6852 (0.096)
ln *C*	−0.0567	−0.3934 (0.695)	−0.0667	−0.3981 (0.692)
Intercept	7.8959	32.9239 (0.000)	8.3102	19.2156 (0.000)
Equation diagnosis				
R^2	0.8980		0.8970	
F	75.3320(0.000)		74.4860(0.000)	
LM(12)	16.2102(0.182)		15.7219(0.204)	
ARCH(1)	0.0485(0.826)		0.0162(0.899)	
DW	2.1572		2.1436	
CUSUM	Stable		Stable	
CUSUMSQ	Stable		Stable	

In the long term, the substitution price elasticity of coal to oil demand is relatively small in China. The long-term price elasticity is −0.0567, which is evidence for our understanding that the coal price has an influence on the oil price elasticity, but the substitution elasticity is comparatively small and not outstanding according to the statistics. So, we believe that the coal substitution is very low. Then, is there a relationship between the low substitution and China's high external dependence on oil (50 %) in recent times? We calculate the production elasticity of coal to oil, in which a 1 % rise in the coal price increases oil production by about 0.0432 % (0.039). Although there is a low substitution effect, it has a relatively large and positive coefficient, so we determine that the substitution of coal production plays a bigger role in oil production than the price of coal.

After we adjust the crude oil and coal prices using PPI, the change in the crude oil price elasticity is small at −0.2284 while the gross industrial output value coefficient drops to 0.4742. It is easy to see that PPI has some influence on oil demand. At the same time, we use industrial value added as a proxy variable to take the place of the gross industrial output value mentioned above in order to improve the reliability of the results. The long-term oil price elasticity is −0.05577 (0.013), so we can see that by using the industrial incremental value, the oil price elasticity becomes smaller. At the same time, the long-term coefficients of the incremental value and coal price are 0.4626 (0.000) and −0.0383 (0.403), respectively.

We address the contribution of the gross industrial output value and oil price in oil demand. Using Eq. 6.2, we decompose the equation variables and get the oil demand influenced by the gross industrial output values and oil prices between 2002 and 2009. But to what degree do these factors influence oil demand? To what degree does a rise in oil prices affect oil demand? We base our conclusions on the results shown in Table 6.4 and according to Warner (1994).

From our analysis, we find that total oil consumption in January 2002 increased 65.29 % by July 2009. By comparison and based on the needs of industrial production, the oil price increased by 158.18 % and the oil demand increased by 124.24 %. At the same time, oil prices went up by 100.95 %, leading to a −32.67 % change in oil consumption; or, to put it another way, the rise in oil prices restricted oil demand by 32.67 %. So, we can draw the conclusion that the growth of industrial production needs far more oil than that required after the inhibiting actions caused by a rise in oil prices. Chinese industrial production increased almost 30 times during the period from 1978 to 2009, along with a 3.25 times increase in oil consumption, so the oil demand increased throughout the period despite the huge rise in prices. This observation shows that the expression "The more oil prices rise, the greater is the demand for oil" is false.

Considering the effects of seasonal factors on the monthly data, this chapter makes some seasonal adjustments about oil demand and gross industrial output value; however the oil price still has some errors because of the seasonal effects. Therefore, we disaggregate the corresponding monthly variables. Take the period from January to July in 2009, as an example, and compare it to the same period in 2002. Oil demand increased by 48.26 % on average, in which the gross industrial output value increased by 135.25 % and the oil demand for industrial production

Table 6.4 Contribution of the variables in oil demand

Variable	Coefficient	Change	Coefficient* Change	Percentage (%)
Panel A: July 2009 and January 2002				
ln *D*	1	0.6529	0.6529	100.0000
ln *Y*	0.5128	1.5818	0.8111	124.2351
ln *P*	−0.2113	1.0095	−0.2133	−32.6700
Others				8.4349
Panel B: January–July 2009 and January–July 2002				
ln *D*	1	0.4826	0.4826	100.0000
ln *Y*	0.5128	1.3525	0.6936	143.7306
ln *P*	−0.2113	0.5961	−0.1260	−26.1020
Others				−17.6285

went up by 143.73 % while the oil demand decreased by 26.10 % in response to increasing prices. From these figures we can see that the longer the time period, the greater is the need for oil due to industrial production, and this need is greater than the inhibiting effects of higher prices. As a result, with the fast economic development in China, the elasticity of oil demand prices has a much smaller inhibiting influence on oil demand than the increase in economic development.

We can determine from Table 6.4 that there are other factors (representing 8.43 %) that affected the increase in oil demand in July 2009 compared to the corresponding period in 2002. We list them as follows: (1) This chapter uses the gross industrial output value, which represented 43 % of GDP in 2008 while the primary industry took up 11 %; construction accounted for 6 % and the tertiary industry accounted for 40 %, so oil demand can also be affected by the construction and tertiary industries, despite the fact that oil is consumed mostly in industrial production and the oil intensity in the tertiary industry is extraordinarily low (but it can increase oil demand to some extent) and (2) In recent years, the oil reserve strategy in China is also a comparatively big factor that affects oil demand, in addition to gross industrial output values, oil and coal prices, PPI, and the construction and tertiary industries. The oil demand in this chapter includes imports and exports; therefore, imports used as oil reserves are included as well. Moreover, there is waste, which is ubiquitous and can also influence oil demand. Furthermore, high-energy consuming but low-productivity industries are a factor that cannot be ignored (Table 6.5).

6.3.2 *Analysis of Crude Oil Demand Elasticity in the Short Run*

In the short term, oil demand has lag effects, which means that a 1 % increase this month will lead to an oil demand drop next month. Let us look at the oil demand

Table 6.5 Short-term price elasticity of Chinese oil

Parameter	Equation 1		Equation 2	
	Coefficient	T statistics	Coefficient	T statistics
Δ ln $Dt-1$	−0.5983	−3.8742(0.000)	−0.6015	−3.8690(0.000)
Δ ln D_{t-1}	−0.3054	−2.8235(0.006)	−0.2979	−2.7469(0.007)
Δ ln Y	0.1990	2.4831(0.015)	0.1761	2.2933(0.025)
Δ ln P	−0.1563	−2.5653(0.012)	−0.1558	−2.4923(0.015)
Δ ln P_{t-1}	0.1320	2.2617(0.026)	0.1366	2.3227(0.023)
Δ ln C_{p-1}	0.1834	3.0590(0.003)	0.1872	3.0688(0.003)
Δ ln C	−0.0220	−0.3761(0.708)	−0.0248	−0.3803(0.705)
Intercept	3.0636	2.2402(0.028)	3.0859	2.1959(0.031)
ECM_{t-1}	−0.3880	−2.2393(0.028)	−0.3713	−2.1320(0.036)
Short-term industrial elasticity 0.1990				
Price elasticity in current month: −0.1563 Lagging results of short-term price elasticity: 0.1591				

caused by a short-term increase in industrial production: when industrial development increases by 1 % this month, it will bring about a 0.1990 % increase in oil consumption. The short-term price elasticity for the month has a negative relationship with oil demand, which is −0.1563. However, the total adds up to 0.1591 because of the lag effect of price, revealing that price has a positive elasticity with oil demand; that is, oil demand rises with increasing prices and a 1 % increase in the oil price will increase oil demand by 0.1591 %.

Apparently, there is a vast difference between the short-term and long-term elasticity of oil. The industrial short-term elasticity is less than the long-term elasticity because industrial production is for the long term, so it needs a relatively long time to react to changes in oil prices and oil demand. In the long term, oil demand has a negative relationship with price, which is in accordance with general economic laws. However, in the short term, higher oil prices increase demand unexpectedly because the price has a lag effect, despite the fact that the month's demand elasticity is −0.1563, which is less than the long-term elasticity, and the short-term price elasticity is 0.1990.

We believe that oil demand is mainly affected by domestic industrial production and that the international oil price has little effect on oil demand, creating the slogan "the higher the international oil price, the greater the imports of oil." In the meantime, oil imports in China play a big part in terms of spot goods, whose prices are the average price during arrival and departure at a particular port. Thus, international investors always drive-up prices during this period, leading to higher oil prices on the spot market than in ordinary markets. On the other hand, China's external dependence on oil is extremely high (already over 51 %), so oil demand in the short term is very high. Moreover, the Chinese people expect rising prices due to both rapid development in recent years and the overall rise in international oil prices. From the analytical results, both the effects of an oil price lag of two months and the elasticity are positive, at 0.1320 and 0.1834, respectively. However, the price elasticity for our month in question is −0.1563, meaning that the oil demand price will be lower as one gets closer to our month. Although a rise in price will decrease oil demand, expectations can actually increase the oil demand, so that the demand is not affected by a rise in price.

In the short term, the substitution elasticity of coal to oil demand is −0.022 (this statistic is not significant) and the impact is extraordinarily low. Considering the effects of the short-term elasticity of coal, oil demand will decrease 2.2 % with a 1 % rise in the coal price. This statistic is not significant and the substitution is very low because coal is the major energy consumed in China while oil has a high external dependence of 51 %.

The reason why the substitution of coal for oil is low is that oil has specific uses in many industries and transportation sectors, so coal cannot replace oil (the substitution is zero in some industries). On the other hand, industrial coal consumption was responsible for 68.7 % of the total energy demand in 2008 while only 18.7 % related to oil. According to the substitution theory, even if these two types of energy could replace each other, there must be an optimum proportional allocation. Once the optimum proportion is surpassed, the substitution elasticity will become weaker in the future. Because of natural conditions and national policies in China, coal production is the largest in the world, leading to an extremely high coal consumption level relative to the rest of the world. In 2008, coal represented 29.25 % of the world's energy consumption, 24.58 % of the total U.S. energy consumption, and 53.40 % of India's total energy consumption (BP 2009). As a result, the substitution elasticity of coal appears to be very low.

We find that the short-term price elasticity, which is adjusted by PPI, is relatively similar to the original calculation without an adjustment (−0.1558) and that the accumulated elasticity is 0.1680. At the same time, after adjusting the total gross industrial output value into industrial add output, the price elasticity for our month is −0.1300 and the accumulated elasticity is 0.1926.

In addition, to analyze the relationship between the short-term price and oil demand and further analyze if this relationship is caused by the insensitivity of the domestic oil price to the international price, this chapter calculates the elasticity of the oil price in Daqing to that for Brent during the period from January 2002 to July 2009, which is 0.9845. It is obvious that the ratio of prices is close to unity, so the elasticity almost equals 1. In terms of the same quality of oil under the same market mechanisms, the cross price elasticity should be 1 if any two oil products are sold in the same place at same time. Nevertheless, the price in Daqing is sensitive to that in Brent, showing that the price in China's oil market is beginning to align with the international price. But we cannot overlook the fact that there is rapid economic development in China, in which the oil demand is increasing substantially, and that the needs of industrial economic development far exceed the inhibiting factor of price, so it is natural to find both higher prices and higher demand.

We find that our oil long-term price elasticity is relatively low compared with that in the developed countries and the average world level (after comparing the

Table 6.6 Comparison of oil price elasticity by country and region

Author	Country	Method	Data	Price elasticity
Eltony and Al-Mutairi (1995)	Kuwait	Cointegration	1970–1989 Gas price annual data	−0.234
Cooper (2003)	US	Multiple regression	1971–2000 Crude oil price annual data	−0.453
Cooper (2003)	France	Multiple regression	1971–2000 Crude oil price annual data	−0.568
Krichene (2005)	World	Cointegration	1918–1973 Crude oil price annual data	−0.32
Krichene (2005)	World	Cointegration	1974–2004 Crude oil price annual data	−0.26
This book	China	Boundary test ARDL	2002.1–2009.7 Crude oil price annual data	−0.2113

Data source organized by the authors

price elasticities in all countries). We believe that the following reasons play a major role: (1) coal is the major energy in China. In other countries, such as the US and UK, oil consumption accounts for 40 % of the total energy use (BP 2009), which is double that of coal consumption, so the substitution elasticity of coal is very small in China, (2) other energy substitution is comparatively low due to the small amount of oil consumption, which lacks elasticity because of rapid economic development and substantial oil demand, and (3) the Chinese oil market mainly consists of three major companies—Sinopec, CNPC (China National Petroleum Corporation) and CNOOC (China National Offshore Oil Corporation)—and their management operations are located in the north, south, and coastal waters. There is corporate integration of upstream and downstream facilities, as well as between companies and businesses, so there is little competition in the energy industry. With the addition of price regulations, oil lacks any elasticity as a whole (Table 6.6).

6.4 Conclusions and Implications

On the basis of bounds testing and ARDL by Pesaran and Pesaran (1997) and Pesaran et al. (2001), this chapter adopts monthly data to analyze the Chinese oil demand price elasticity and the substitution elasticity of coal to oil. The results are outlined below:

(1) Oil demand is mainly driven by gross industrial output and it can be restrained by rising prices, and coal has a low substitution price elasticity. In addition, the increase in demand by gross industrial output is bigger than the restraints of price. When the gross industrial output value increases by 1 %, the oil demand increases by virtually 93.669 thousand tons. However, when the real oil price increases by 1 %, the oil demand decreases by 38.592 thousand tons. This variation in responses illustrates why the gross industrial output value increased by 124.24 % of oil demand and oil demand fell about 32.67 % due to rising prices in July 2009 compared with January 2002. This proves that the oil demand price elasticity is far less than the effect of the industrial income elasticity. Moreover, coal has a weak substitution price elasticity (−0.0567), which is not significant, as well as a weak and low substitutability in the long term because of strong specifications for particular oil products that cannot be substituted by coal. Further, coal use represented 68.7 % of the total energy use in 2008 while oil consumption was only 18.7 %, the substitution of oil by coal transcends the optimal proportional distribution and the substitution elasticity is weak.

(2) Short-term oil consumption has lagged effects; namely, an increase in demand this month will decrease demand next month and the industrial income elasticity for the short term is less than that for the long term. This reveals a long process in industrial production and reflects a comparatively long process in terms of oil demand. In the short term, the current price elasticity (−0.1563) is less than that in the long term, but the short-term accumulated elasticity is positive, showing that there is an unreasonable situation in terms of the oil demand in China. As a result, the means of oil supply need to be improved and the supply of wide varieties like futures should be enhanced. In the meantime, we should reduce the purchase of spot goods. Another factor to consider is that, in the short term, coal has a low substitution elasticity, which equals 0.22 (not statistically significant), so its influence is poor.

According to our research, we make the following suggestions:

(1) Oil demand in China is driven by economic development and high income elasticities. In addition, large and energy-intensive industries account for a significant proportion of the demand. As a consequence, we should follow a growth path that decreases the energy intensity and develops more conservative, low-energy consuming, and resource-conserving industries to reduce the elasticity of incomes or output to oil demand.

(2) Rising oil prices have inhibited oil demand, but without such increases, oil demand would have continued to increase substantially. However, compared with the developed countries, the oil demand elasticity is still relatively low in China, so the country needs to strengthen its market mechanisms and provide information transparency and fluidity, so that they are more sensitive to the oil price and crude oil demand.

References

Bentzen J, Engsted T (1993) Short- and long-run elasticities in energy demand: a cointegration approach. Energy Econ 15(1):9–16

BP (2009) World energy statistical review 2009. BP, London

Cooper JCB (2003) Price elasticity of demand for crude oil: estimates for 23 countries. OPEC Rev 27(1):1–8

Eltony MN, Al-Mutairi NH (1995) Demand for gasoline in Kuwait: an empirical analysis using cointegration techniques. Energy Econ 17(3):249–253

IEA (2006) World energy outlook 2006. International Energy Agency (IEA), Paris

Johansen S, Juselius K (1990) Maximum likelihood estimation and inference on cointegration with applications to the demand for money. Oxford Bull Econ Stat 52(2):169–210

Krichene N (2005) A simultaneous equation model for world crude oil and natural gas markets. International Monetary Fund (IMF)

Pesaran MH, Pesaran B (1997) Working with Microfit 4.0 interactive econometric analysis. Oxford University Press, Oxford

Pesaran MH, Shin Y, Smith RJ (2001) Bounds testing approaches to the analysis of level relationships. J Appl Econometrics 16(3):289–326

Ramcharran H (2002) Oil production responses to price changes: an empirical application of the competitive model to OPEC and non-OPEC countries. Energy Econ 24(2):97–106

Sandbach J (1988) The sensitivity of consumption of oil products to price changes: an econometric investigation. Energy Econ 10(4):261–270

Warner AM (1994) Does world investment demand determine U.S. exports. Am Econ Rev 84 (5):1409–1422

Chapter 7
China's Regional Energy Efficiency

Regional development is unbalanced in China, and there are differences in regional energy efficiency. Planning based on regional development is an important part of our current and future development policies. At present, the Chinese government is drawing up its "Twelfth Five-Year Plan," in which energy conservation and carbon emissions reduction targets for different regions and the country as a whole are projected to be fulfilled by 2020. In Chap. 2, we mentioned that on the basis of the types of power supply and coal consumption (using the equivalent value method), the method of using the regional unit of GDP in terms of measuring the differences and changes in energy efficiency in different areas has certain limitations and biases. Therefore, based on the theories and research methods learned from Chap. 2, in this chapter, we conduct some empirical research on Chinese regional energy efficiency and focus on several key questions, as follows (Liao 2008):

- To what extent are China's different regional macro energy efficiencies (energy consumption per unit of GDP) caused by differences in the three major industrial structures and what are the subjective or objective reasons for these differences?
- How big are the differences in utilization efficiencies of the energy factors and what causes these differences in terms of both subjective and objective reasons?
- What are the differences in adopting different methods in terms of regional energy consumption and what can we learn from them?

In addition, we will apply an exploratory method in this chapter using some dynamic data, including an analytical method (Malmquist Index), to study the energy efficiency of the iron and steel sector.

Y.-M. Wei and H. Liao, *Energy Economics: Energy Efficiency in China*,
DOI 10.1007/978-3-319-44631-8_7

7.1 Decomposition Study of Regional Energy Macro Efficiency

Chapter 3 applied the Divisia decomposition method to study the changes in the industrial structure of the macro energy efficiency over time. However, from the spatial dimension, the Chinese regional industrial structure varies significantly, which causes differences to a certain degree in the regional macro energy efficiency (energy consumption per unit of GDP). The research literature about the regional differences in energy efficiency and decomposition is relatively small, including that of other countries and regions, such as Alcantara and Duro's (2004) study of the OECD countries. Here, to accurately unify the relevant statements and classify the factors that affect the differences in regional energy consumption per unit of GDP into structure effects and intensity effects (i.e. energy consumption per value added by industry), we will pre-process the value added of the sector of conversion and the processing and total energy consumption in each region.

7.1.1 Theil Index Decomposition Method

During the process of comparing the differences in regional energy consumption per unit of GDP in different areas, we need to consider the regional weighting factors. For example, the energy consumption per unit of GDP in Shandong was 12.31 thousand tons of coal equivalent (tce) per ten thousand yuan in 2006 (according to the prices in 2005). However, the data for Ningxia was 40.99 thousand tce per ten thousand yuan, which is more than three times that of Shandong (NBS 2007). Nonetheless, the total energy consumption of Ningxia province is very low, accounting for only 11 % of the total amount of Shandong province. From the perspective of absolute value, the potential for energy conservation in Ningxia may not be greater than that in Shandong. The contribution that the energy consumption per unit of GDP in Ningxia makes to the differences in regional energy consumption per unit of GDP may not be significant. During the process of calculating the regional differences, the conclusions may be biased if the different weights are not considered in the calculation of regional differences.

Based on the method used to calculate the energy consumption per unit of GDP, GDP is the value of the various production sectors. The energy consumption is composed of the industrial and residential sectors. In China, the industrial sector is the main energy consuming sector. Here, in the decomposition of the regional differences in the energy consumption per unit of GDP, we do not include residential energy consumption (i.e., where the energy consumption per unit of GDP is the inverse of energy productivity).

Some frequently used decomposition methods include the Gini index (Dalton 1920; Gini 1921) and the Theil index (Theil 1967). To comprehensively classify the differences according to both the internal and external differences, we employ the

Theil index. In general, the more specifically the industries are classified, the more accurate are the results. Except for some areas in China, most regions do not have the relevant energy consumption data classified according to the various industries. Based on the availability of data, our classification is according to three major industries (primary, secondary, and tertiary). T_A, the differences within the group, means the differences of regional energy consumption per unit of GDP caused by the differences of energy consumption per value added within the industries while T_B, the group differences, means the differences of regional energy consumption per unit of GDP caused by the regional differences in industrial structure.

Provided that E_{ij} stands for the energy consumption of industry i in region j, V_{ij} means the value added of industry i in region j. E_i means the total energy consumption of sector i (the summation of all regions). V_i means the value added of industry i (the summation of all regions). E_j means the total regional energy consumption of the three major industries. V_j means the value added of the three major industries in region j. E means the total energy consumption of the whole country, while V means the value added of the three major industries in the whole country. Then, we get the Theil index:

$$T = T_A + T_B \tag{7.1}$$

T_A means the differences in energy consumption per value added (the differences within the group):

$$T_A = \underbrace{\frac{E_1}{E}\left[\sum_{j=1}^{30}\frac{E_{1,j}}{E_1}\cdot\ln\frac{E_{1,j}/E_1}{V_{1,j}/V_1}\right]}_{\text{Primary industry}} + \underbrace{\frac{E_2}{E}\left[\sum_{i=1}^{30}\frac{E_{2,j}}{E_2}\cdot\ln\frac{E_{2,j}/E_2}{V_{2,j}/V_2}\right]}_{\text{Secondary industry}} + \underbrace{\frac{E_3}{E}\left[\sum_{i=1}^{30}\frac{E_{3,j}}{E_3}\cdot\ln\frac{E_{3,j}/E_3}{V_{3,j}/V_3}\right]}_{\text{Tertiary industry}} \tag{7.2}$$

T_B means the differences in energy consumption per value added in the three major industries (the differences between the groups):

$$T_B = \sum_{i=1}^{3}\frac{E_i}{E}\cdot\ln\frac{E_i/E}{V_i/V} \tag{7.3}$$

7.1.2 Data Sources and Processing

When using the energy data, a part of the primary energy may need to be converted and processed before entering it in the end-use sectors. For example, approximately 50 % of the coal in China is used to generate electricity, with an efficiency of 35 %. Due to the fact that some of the electricity is transferred across several regions (such as Guangdong province, where the electricity used is from other provinces and cities), we can get a biased result when we convert the electricity delivered into and out of the area according to its coal equivalent measure using the electrical equivalent method and the coal consumption method. In fact, if we adopt the calorific value calculation, we deem the power generation wastage as a part of the energy consumption of a particular area's power inputs, which may overestimate the energy efficiency of the originating area from which the electricity was delivered (imported) to satisfy the area's energy demand. However, if we adopt the coal consumption method, we should deem the value added of the power generation industry in the power output (or originating) area as the value added of the power input area to unify the calibrations. However, it is difficult to get the relevant data, and this situation is not uncommon within the petroleum processing and coal conversion processing sectors.

To unify the data, the regional industrial sectors exclude the four energy processing and conversion industries[1]: petroleum processing, coking, and nuclear fuel processing industries; thermal power production industries; heat production and supply industries; gas production and supply industries. The energy data comes from the regional energy balance sheets within *China's Energy Statistical Yearbook 2007* (NBS-DE and NBE-DCS 2009). As Fig. 7.1 shows, among the regional energy consumption of the three major industries, the secondary industry (mainly the industrial sector) accounts for the largest part while the primary industry represents a relatively small part of the whole (excluding the use of biomass in the countryside).

7.1.3 Results and Discussion

The regional differences in energy consumption per unit of GDP are shown in Fig. 7.1. There are some differences between the results caused by considering the value added and energy consumption as respective weights, but this is not serious. When adopting the energy consumption as the weight, approximately 70.8 % of the differences in regional energy consumption per unit of GDP (energy macro efficiency) are caused by the (group) differences between the structures of the three major industries while the differences within the groups are relatively small and the contribution that the differences of energy consumption per value added make to the differences of regional energy consumption per unit of GDP is 26.3 %. In addition,

[1]Industrial value added, which is classified according to the major categories of the industrial sector in 2006, is the value added of all state-owned and large-scale non-state-owned industrial enterprises. However, according to the first national economic census and other data, the total output and the above-designated size of the total output of these four industries are not very different, which means that most enterprises within these four industries are "all state-owned industrial enterprises and large-scale non-state-owned industrial enterprises."

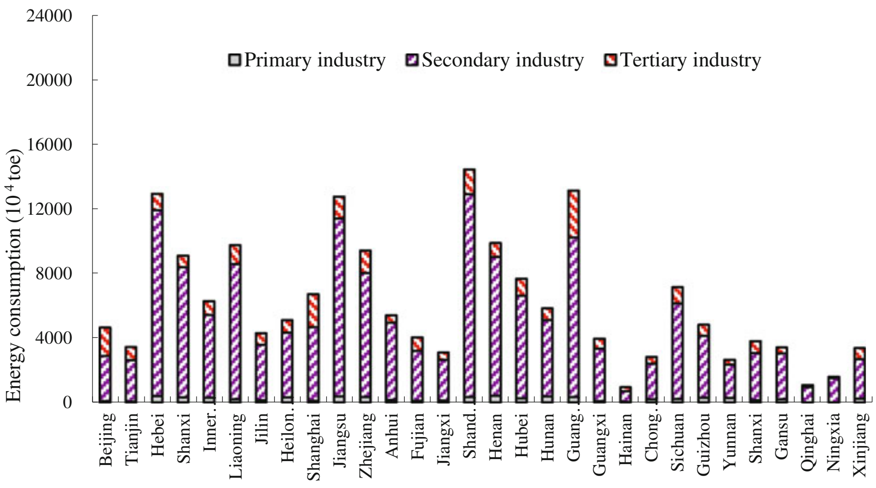

Fig. 7.1 Regional energy consumption in the three major industries (2006). *Data source* authors' calculations. The energy processing and conversion sectors are excluded in the secondary industry

the contribution that the primary and tertiary industries make is much smaller. At present, the differences between the structures of the three major industries are relatively large. As Fig. 7.2 shows (NBS 2007; NBS-DITS 2007), if the data are available, by decomposing the energy consumption per value added of the regional industrial sectors one step further, we can get the contribution made by the differences of the energy consumption per value added of the industrial structure, as well as that within the various industries (Table 7.1).

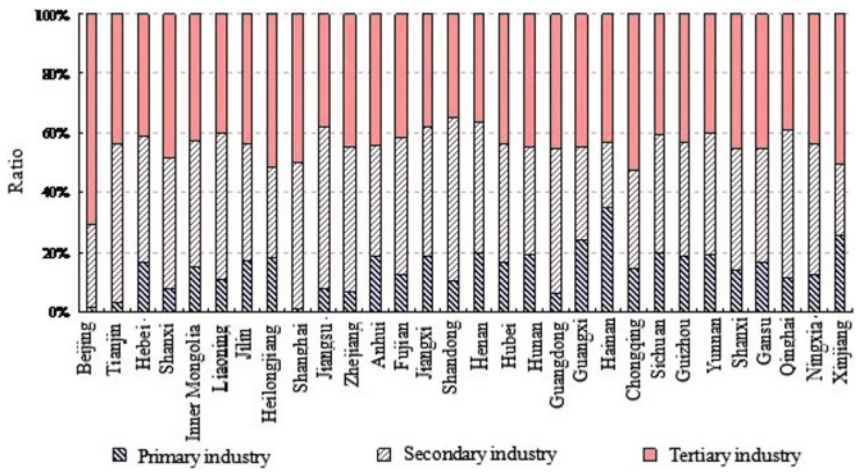

Fig. 7.2 China's three major industrial structures by region (2006). *Data sources* NBS (2007b), NBS-DITS (2007) and authors' calculations. The secondary industry excludes energy processing and conversion sector

Table 7.1 China's energy consumption per unit of GDP and the differences in decomposition (2006)

Weight index	Energy consumption		Added value	
	Theil index	Theil index composition (%)	Theil index	Theil index composition (%)
Difference of energy consumption per unit added value in three major industries	0.0511	29.2	0.0385	20.8
# Difference of energy consumption per unit added value in primary industry	0.0016	0.9	0.0054	2.9
# Difference of energy consumption per unit added value in secondary industry	0.0461	26.3	0.0234	12.7
# Difference of energy consumption per unit added value in tertiary industry	0.0034	1.9	0.0097	5.3
Structural difference of three industries	0.1240	70.8	0.1463	79.2
Total	0.1751	100	0.1848	100

The results show that the difference in industrial structure is the major reason for the difference in the regional energy consumption per unit of GDP. Hence, from this perspective, if the areas that have relatively low energy macro efficiency want to reduce the gap with the areas that have a much higher efficiency, they should focus on adjusting the structure of the three major industries. In addition, these regions ought to consider the actual situation. For example, some areas in western China with a high proportion of agriculture have a relatively low proportion of industry. For these areas, the most important thing is to try to decrease the proportion of agriculture, accelerate the pace of the industrialization process, and increase the proportion of the tertiary industry. Limited by their different stages of development, historical backgrounds, and natural and human resources, in combination with the national industrial layout, the existence of differences in regional energy macro efficiency is not totally unreasonable and unacceptable.

7.1.4 Econometric Analysis of Differences in Regional Energy Macro Efficiency

In this section, we will analyze the causes behind the regional differences in energy consumption per unit of GDP through the regression model. Because of cost advantages and other reasons, areas abundant in natural resources tend to develop energy-intensive industries (excluding the processing and conversion industry). Not only does resource endowment relate to the energy reserve, it also relates to the difficulties of energy exploitation and other factors. Here, we will use the energy self-sufficiency rate to reflect the degree of resource endowments. What can be forecast is that in terms of the regression results, the estimated value of the energy self-sufficiency is positive.

The market-oriented economic reform has played an active role in improving the energy economic efficiency (Liao 2008). Therefore, we will introduce the variables of the marketization index. The data from Fan et al. (2006), who adopted the principal component analysis method to get the regional marketization index, comprise 23 basic indicators involved in the relationship between government and market, including the development of non-state-owned economies, the degree of development of the product market, the degree of development of the factor market, the development of the market intermediary organizations, and the environment of the legal system. According to this index, Shanghai has the highest degree of marketization followed by Guangdong, Zhejiang, and Jiangsu, while Qinghai has the lowest. Here, we need to determine the marketization index (maximum value equals 100). The outstanding performance of the Chinese economic structural reform is reflected in the fact that public ownership dominates, along with the significant development of other kinds of ownership and the decrease in the proportion of the state-owned economy. Therefore, the Chinese government has introduced the proportion index of the state-owned economy (the proportion of the value added of state-owned and state-controlled enterprises to that of large industries) as the proxy variable to reflect the process of marketization. However, this does not mean that there is a direct relationship between the state-owned economy and energy efficiency (during a given period, the two factors have a strong correlation). What can be anticipated is that in the regression results, the estimated value of the index of marketization is positive, whereas the coefficient of the proportion of the state-owned economy is negative. It can be said that if the other conditions remain unchanged, then the higher the degree of marketization, the lower is the energy consumption per unit of GDP. Foreign trade is conducive to the introduction of advanced technology and management methods from abroad, which may also be an important factor that affects the energy consumption per unit of GDP after the introduction of the foreign trade dependent variables. It can be expected that the estimated values of the economic weighted coefficients are positive in the regression results.

Table 7.2 illustrates the regression results. The model numbers I–VII show the results of regressing the logarithm of the energy consumption per unit of GDP. The results are similar when considering either the value added or energy as the weight.

In model I, the F-statistics test shows that the two factors—the index of marketization and energy self-sufficiency rate—are significant among the statistics while the initial degree is not [p-value = 0.476]. However, the three factors are jointly significant, partially because when generating the marketization index, the initial degree is included. The results of model I illustrate that ceteris paribus, when the marketization index increases by one unit, the energy consumption per unit of GDP will decrease by 1.9 %, meaning that an increase in marketization helps decrease the energy consumption per unit of GDP. In model II, after eliminating the dependence on the foreign trade variable, the proxy results of energy self-sufficiency and the marketization index remain unchanged. The coefficient R^2 for the models I and II is approximately 70 %, which means that the three independent variables can explain approximately 70 % of the regional differences in energy consumption per unit of GDP (strictly speaking, it is the difference in the values). In the regions with a low

Table 7.2 Impact factors of energy consumption differences per unit of value added in China (2006)

Model No.	Major three industries (excluding energy processing conversion)								Industrial sector (excluding energy processing conversion)					
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV
Weight	$\sqrt{\ln V_j}$				$\sqrt{\ln E_j}$				$\sqrt{\ln V_{2,j}}$		$\sqrt{\ln E_{2,j}}$		$\sqrt{\ln V_{2,j}}$	$\sqrt{\ln E_{2,j}}$
Intercept term	1.3969	1.2864	−0.0289	0.3314	1.4451	1.3247	−0.0210	0.3518	2.7841	2.9088	2.8609	2.9510	0.7265	0.7086
	(0.3099)	(0.2068)	(0.1537)	(0.0847)	(0.3146)	(0.2120)	(0.1581)	(0.0881)	(0.3986)	(0.2288)	(0.4275)	(0.2469)	(0.2131)	(0.2309)
	[0.0001]	[0.0000]	[0.8523]	[0.0006]	[0.0001]	[0.0000]	[0.8951]	[0.0005]	[0.0000]	[0.0000]	[0.0000]	[0.0000]	[0.0021]	[0.0050]
Opening degree (%)	0.0010		−0.0033	−0.0046	0.0011		−0.0034	−0.0048	−0.0011		−0.0008		−0.0062	−0.0062
	(0.0013)		(0.0009)	(0.0008)	(0.0014)		(0.0009)	(0.0009)	(0.0019)		(0.0020)		(0.0011)	(0.0012)
	[0.4764]		[0.0009]	[0.0000]	[0.4312]		[0.0010]	[0.0000]	[0.5736]		[0.6907]		[0.0000]	[0.0000]
Energy self-sufficiency (%)	0.0007	0.0007	0.0008	0.0010	0.0006	0.0007	0.0008	0.0009	0.0005	0.0005	0.0005	0.0005	0.0007	0.0007
	(0.0001)	(0.0001)	(0.0001)	(0.0002)	(0.0001	(0.0001)	(0.0001)	(0.0002)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
	[0.0000]	[0.0000]	[0.0000]	[0.0000]	[0.0000]	[0.0000]	[0.0000]	[0.0000]	[0.0000]	[0.0000]	[0.0001]	[0.0000]	[0.0000]	[0.0000]
Marketization index	−0.0194	−0.0171			−0.0200	−0.0175			−0.0259	−0.0285	−0.0270	−0.0289		
	(0.0051)	(0.0026)			(0.0051)	(0.0027)			(0.0067)	(0.0029)	(0.0072)	(0.0032)		
	[0.0007]	[0.0000]			[0.0006]	[0.0000]			[0.0006]	[0.0000]	[0.0009]	[0.0000]		
Ratio of state-owned economy (%)			0.0067		1.4451		0.0069						0.0117	0.0125
			(0.0025)		(0.3146)		(0.0025)						(0.0040)	(0.0043)
			[0.0135]		[0.0001]		[0.0120]						[0.0071]	[0.0079]
R^2	0.6851	0.6817	0.5880	0.5178	0.6861	0.6821	0.5818	0.5098	0.7920	0.7899	0.7762	0.7750	0.7479	0.7324
$\bar{R}^2$	0.6487	0.6581	0.5404	0.4863	0.6499	0.6585	0.5335	0.4734	0.7680	0.7743	0.7503	0.7583	0.7188	0.7015
F-statistics	18.8536	28.9121	12.3678	14.4985	18.9467	28.9606	12.0566	14.0370	33.0049	50.7476	30.0526	46.4946	25.7094	23.7210
p-value	[0.0000]	[0.0000]	[0.0000]	[0.0001]	[0.0000]	[0.0000]	[0.0000]	[0.0001]	[0.0000]	[0.0000]	[0.0000]	[0.0000]	[0.0000]	[0.0000]

Description: The dependent variable is the logarithm of the regional units that increase the value of energy consumption. Estimated using weighted least squares (WLS) and an adjusted White test for heteroscedasticity. Parentheses are standard deviation. Square brackets are the p-value degree of marketization, the intervention efforts of municipal governments are significant, which results in a high proportion of high-energy consumption industries with a low productivity. From regional development strategies during the Tenth Five-Year Plan (2000), many regions, especially the central and western regions of China, tended to vigorously develop high-energy consumption industries.

If we adopt the proportion of the state-owned economy as the measure of the degree of marketization, instead of the variable of the marketization index, the basic conclusion is the same according to the results from models III and IV while the proxy for the dependence on foreign trade is negative and much more significant. This is mainly because the correlation between the proportion of the state-owned economy and the dependence on foreign trade is relatively low (absolute value). Keeping other factors constant, increasing the dependence on foreign trade by one percentage point will shrink the energy consumption per unit of GDP by approximately 0.33 %. The higher the dependence on foreign trade, the better is the energy macro efficiency (the energy consumption per unit of GDP is low), which means that expanding the degree of openness to the outside world makes a great contribution to improving the energy efficiency. The regression models I–IV show that the proxy of the energy self-sufficiency rate demonstrates great stability and increasing the self-sufficiency rate by one percentage point will decrease the energy consumption per unit of GDP by approximately 0.08 %. Because of comparative advantages, transportation costs, national industrial networks, and so on, the areas with rich energy resources tend to develop high-energy consumption industries. Therefore, it is reasonable that the level of energy consumption per unit of GDP in these areas is relatively high.

In this section, we also regress the factors that influence the energy consumption per value added of the industrial sectors (in models IX–XIV and model VI), and the conclusion is basically the same. The results of the overall research on the three major industries and the variable of the proportion of the state-owned economy are much more significant (mainly because we adopt the proportion of the industrial value added of the state-owned and state-controlled large-scale enterprises to that of all large-scale enterprises in our measurement). As a result, the explanatory power of the models increases (R^2 = 70–80 %). According to model IX (ceteris paribus), when the energy self-sufficiency rate and marketization index increase by one percentage point, the value added of industry will increase 0.05 % and decrease 2.59 %, respectively. This regression analysis shows that from the gross macro perspective, improving the degree of marketization and the level of openness to the outside world has an important and positive effect on increasing the energy industry's macro efficiency.

7.2 Comparison of Regional Energy Utilization Efficiencies

The most common way to compare the regional energy efficiencies is to adopt the energy macro efficiency index (energy consumption per unit of value added) because it is easy to calculate and readily available. However, energy macro efficiency is a biased index, which ignores the substitutability of other factors, such as capital and labor, as well as the effect of the national industrial layout. For example, although the level of energy consumption is low in some areas, the financial and software industries are more developed, and they represent the power of human capital, which is a pillar of local industries. At the current stage of development in China, it is impossible to develop the financial and software industries in all regions of the country. Comparing the regional energy macro efficiencies under such circumstances may overstate the energy-conserving potential of the areas with low energy macro efficiency. This section will include the data envelopment analysis (DEA) presented in Chap. 2 to study the regional elements of energy-use efficiency and the indicators of macro efficiency by industrial sector and to analyze the causes of the differences.

7.2.1 Data Sources and Processing

This section will focus on the large-scale industrial enterprises[2] in 30 provinces, municipalities, and autonomous regions.[3] The factor inputs include capital, labor, energy resources, and output, which is calculated as the value added of industry. We will consider the energy resources as natural resources. From the large-scale industry viewpoint, energy includes both the input factors and the finished products. Hence, similar to Sect. 6.1, the industry being discussed here excludes coal mining, oil and natural gas, hydroelectric power, and nuclear power, which are the four primary energy sectors that are easy to unify in terms of the calibrations. The data are from the *China Industrial Economic Statistical Yearbook 2007* (NBS-DITS 2007), *China Energy Statistical Yearbook 2006* (NBS-DITS and NDRC-BE 2007), *China Statistical Yearbook 2007* (NBS 2007) and the database of the State Information Center.

The output is represented by value added, and the capital stock is expressed by the annual average net value balances of the fixed assets. We adopt two factors to represent the labor force data: (1) the labor force number and (2) considering the

[2]Excludes Tibet because of unavailable data.

[3]All of the state-owned and large-scale non-state-owned industrial enterprises ("large-scale industry" for short). According to the data of the national economic census in 2004, the total output of the large-scale industry accounts for 91 % of the total industrial output and the proportion is rising. Therefore, we consider the large-scale industry designation to be the same as the total industrial sector.

regional differences in the quality of the labor force, the average salary within the manufacturing industry after the application of purchasing power parity (PPP)[4] is used as the conversion coefficient of labor quality to get the efficiency labor index. The amount of energy inputs can be computed based on the information from the various yearbooks mentioned above (excluding the four energy processing and conversion sectors).

7.2.2 *Results and Discussion*

The data envelopment analysis method (DEA) is given pursuant to Chap. 2 and the data above. The results of the calculations of the utilization efficiency of the regional industrial sector energy factors in 2006 are shown in Table 7.3. For comparison purposes, the table presents the method of coal consumption and energy macro efficiency using thermal equivalents (an index where Guangdong = 1.000), which considers the utilization efficiency of the energy factors but does not consider the regional differences in labor quality.

According to the results, we can make the following conclusions:

(1) Using a variety of methods to calculate the energy efficiency, the regions are arranged by small changes between them and the correlation between the methods is relatively high, as reflected in Fig. 7.3. The efficiency of Guangdong is always the highest (Table 7.4).
(2) Regardless of whether we use the coal consumption method or the thermal equivalent method or whether we consider the differences of labor quality, the regional differences of the energy utilization efficiency are less than that of the energy macro efficiency, which is reflected by the variance coefficient in Fig. 7.3 (if adopting another differences index, we reach the same conclusion). This feature means that the energy macro efficiency is biased. If we adopt the utilization efficiency index and consider the substitutability of energy with other factors, the differences between Ningxia, Shanxi, Guizhou, and other regions with relatively low values and Shanghai and Guangdong, which have high values, will shrink dramatically.
(3) Regardless of whether we use the coal-consumption method or the thermal equivalent method, the differences in the energy utilization efficiency are significantly reduced after considering the regional differences in the quality of labor. When not considering the differences in the quality of labor, the fact that the energy utilization efficiency is relatively high in Beijing and Shanghai is because of their high quality of labor (but not considering labor as a factor input).
(4) Regardless of whether we use the coal-consumption method or the thermal equivalent method, the relevant differences of energy utilization efficiency are

[4]The method of formulating PPP is in Sect. 3.2.

Table 7.3 Utilization efficiency of the energy factors and energy macro-efficiency in China (2006)

Region	Energy macro-efficiency		Utilization efficiency of energy factors (data envelopment analysis)			
	Coal equivalent calculation (A)	Thermal equivalent calculation (B)	Coal equivalent calculation		Thermal equivalent calculation	
			Considering differences of labor quality (C)	Not considering differences of labor quality (D)	Considering differences of labor quality (E)	Not considering differences of labor quality (F)
Guangdong	1.000	1.000	1.000	1.000	1.000	1.000
Shanghai	0.898	0.946	1.000	1.000	1.000	1.000
Tianjin	0.739	0.803	1.000	1.000	1.000	1.000
Jiangsu	0.683	0.745	0.938	0.935	0.935	0.931
Shandong	0.490	0.538	1.000	0.980	1.000	0.970
Chongqing	0.324	0.326	1.000	1.000	1.000	1.000
Hainan	0.261	0.280	1.000	1.000	1.000	1.000
Henan	0.245	0.268	1.000	1.000	1.000	1.000
Inner Mongolia	0.176	0.209	0.506	0.366	0.463	0.334
Yunnan	0.332	0.331	0.723	0.486	0.791	0.528
Beijing	0.803	0.787	0.938	0.857	0.985	0.891
Fujian	0.784	0.784	0.891	0.886	0.894	0.887
Hubei	0.319	0.328	0.758	0.486	0.769	0.513
Hunan	0.386	0.400	0.765	0.810	0.810	0.813
Anhui	0.340	0.380	0.740	0.810	0.727	0.807
Jiangxi	0.393	0.414	0.797	0.749	0.826	0.747
Qinghai	0.288	0.235	0.580	0.438	0.771	0.580
Jilin	0.332	0.362	0.771	0.510	0.772	0.508
Liaoning	0.349	0.371	0.737	0.470	0.760	0.481
Guangxi	0.373	0.364	0.716	0.588	0.754	0.656

(continued)

Table 7.3 (continued)

Region	Energy macro-efficiency		Utilization efficiency of energy factors (data envelopment analysis)			
	Coal equivalent calculation (A)	Thermal equivalent calculation (B)	Coal equivalent calculation		Thermal equivalent calculation	
			Considering differences of labor quality (C)	Not considering differences of labor quality (D)	Considering differences of labor quality (E)	Not considering differences of labor quality (F)
Shaanxi	0.331	0.365	0.734	0.654	0.727	0.645
Zhejiang	0.745	0.743	0.757	0.764	0.763	0.771
Sichuan	0.369	0.367	0.710	0.643	0.782	0.705
Guizhou	0.207	0.229	0.479	0.300	0.474	0.295
Gansu	0.201	0.205	0.425	0.265	0.454	0.281
Hebei	0.234	0.253	0.497	0.435	0.504	0.439
Shanxi	0.128	0.148	0.337	0.208	0.316	0.194
Heilongjiang	0.219	0.243	0.513	0.309	0.505	0.302
Xinjiang	0.109	0.117	0.270	0.189	0.274	0.191
Ningxia	0.110	0.120	0.275	0.187	0.275	0.186
Variance coefficient	0.607	0.592	0.316	0.445	0.312	0.435

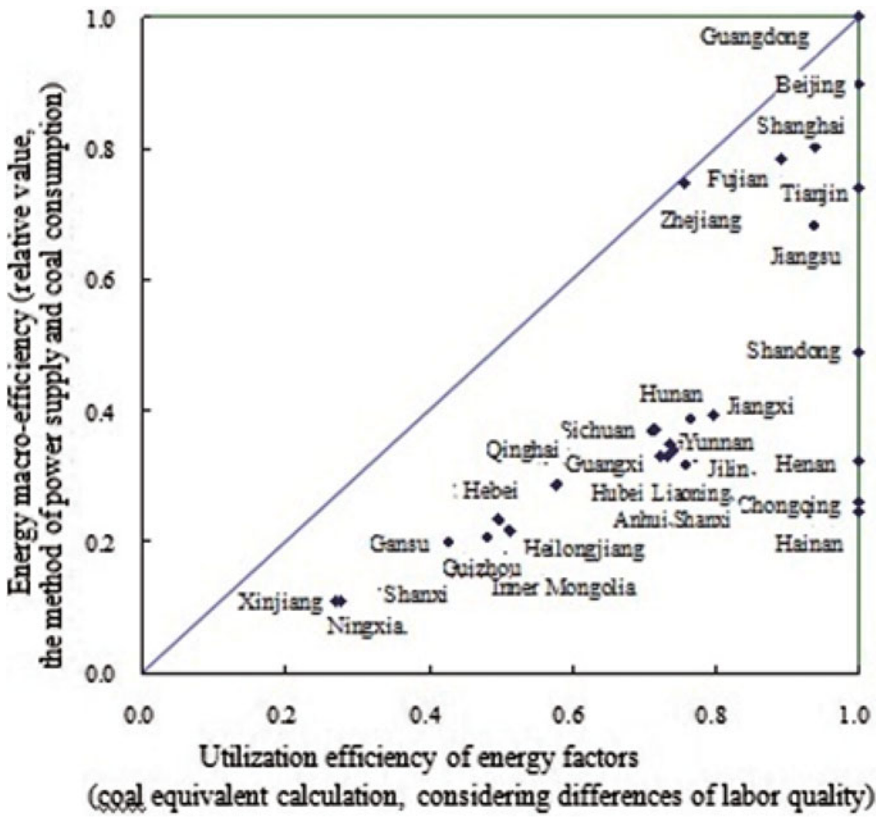

Fig. 7.3 Utilization efficiency of energy factors and energy macro-efficiency in the industrial sectors by region (2006). *Data source* authors' calculations

Table 7.4 Correlation coefficient of the energy efficiency index values in China (2006)

Measurement method	(A)	(B)	(C)	(D)	(E)
(B)	0.996				
(C)	0.698	0.711			
(D)	0.707	0.722	0.953		
(E)	0.689	0.690	0.984	0.928	
(F)	0.710	0.717	0.954	0.994	0.948

not dramatic, which is reflected in the comparison of the variance coefficients between columns C and E and columns D and F. The main reason is that the power transmission volumes between provinces is quite small. In 2006, the net power transmission volume between provinces represented 15.7 % of the total national power consumption.

(5) When considering the differences in the quality of labor and adopting the coal-consumption method (model C), Guangdong, Shanghai, Tianjin,

Shandong, Chongqing, Hainan, and Henan have the highest energy factor-utilization efficiency while Xinjiang, Ningxia, Shanxi, Gansu, Guizhou, and Inner Mongolia, which are located in the western regions of China and have rich energy resources, have the lowest efficiency. As Fig. 7.3 shows, except for Guangdong, all the provinces are located beneath the diagonal, where the intensity of the variable on the horizontal axis is greater than the variable on the vertical axis. This means that by adopting the utilization efficiency index as the measure, the regional differences shrink mainly because of the substitution of energy for capital and labor. The fact that the efficiency of Chongqing, Hainan, Henan, and other regions is relatively high is not coincident with the real situation; thus, the application of the DEA method is critical in terms of data accuracy, which deserves further study. If the energy resources pricing mechanism is unreasonable, then the price of resources would be unacceptably low and result in a low awareness of energy conservation, as well as a low energy factor utilization efficiency.

7.2.3 *Econometric Analysis of the Regional Energy Utilization Efficiency Differences*

By adopting the regression analysis method used in the last section, we can have a discussion on the relationships of the energy utilization efficiency with foreign trade, the energy self-sufficiency rate, and the marketization index (the proportion of the economy represented by the public) to reach the same conclusion. In model I, a joint inspection shows that the coefficients of the three relationships are significant, except for the statistics of the dependence on foreign trade. In the case where the other conditions remain unchanged, when the energy self-sufficiency rate increases by 1 %, its utilization efficiency decreases by 0.06 %, and when the marketization index increases by one unit, its utilization efficiency increases by 1.56 %. When eliminating the variable related to the dependence on foreign trade, the conclusion is basically the same, and the marketization index is more significant (both correlations). When adopting the proportion of the public economy as the measure of the degree of marketization, we arrive at the same conclusion (models III and IV), but the significance of the statistics decreases somewhat. The reason is that there is a correlation between the variables and the marketization process, but there are also some differences (Table 7.5).

The model reveals that when considering the substitution of energy with capital and labor, the energy self-sufficiency rate still has a significant effect on energy efficiency. Compared with the regression results of the energy consumption per unit of GDP obtained in the previous section, both the R^2 coefficients and the significance of the statistics are decreasing. This means that the variables mentioned have a larger explanatory power toward energy macro efficiency than toward energy

Table 7.5 Impact factors of the utilization efficiency of the energy elements in the industrial sectors (2006)

	I	II	III	III
Intercept	−1.2330	−1.0121	−0.0231	0.1100
	(0.3728)	(0.2208)	(0.1892)	(0.1136)
	[0.0028]	[0.0001]	[0.9038]	[0.3414]
Opening degree (%)	−0.0019		0.0013	
	(0.0017)		(0.0009)	
	[0.2705]		[0.1649]	
Energy self-sufficiency (%)	−0.0006	−0.0006	−0.0007	−0.0008
	(0.0001)	(0.0001)	(0.0001)	(0.0001)
	[0.0000]	[0.0000]	[0.0000]	[0.0000]
Marketization index	0.0156	0.0110		
	(0.0062)	(0.0028)		
	[0.0194]	[0.0005]		
Ratio of state-owned economy (%)			−0.0066	−0.0081
			(0.0033)	(0.0025)
			[0.0581]	[0.0035]
R^2	0.5251	0.5064	0.4661	0.4427
$\bar{R}^2$	0.4703	0.4698	0.4045	0.4014
F-statistics	9.5840	13.8504	7.5651	10.7230
p-value	[0.0002]	[0.0001]	[0.0009]	[0.0004]

Dependent variable is the logarithm value of the energy elements' utilization efficiency in the industrial sectors (excluding the energy processing and conversation sectors, and considering differences in labor quality). To avoid and decrease the heteroscedasticity, we used WLS (weighted least squares), where the weight is the logarithmic square root of the total value added (excluding energy processing and conversation sectors). If we use the logarithm value's square root of energy consumption, the result is slightly different, so we did not list it in table. Standard deviation is in ( ) and p-value is in [ ]; both are adjusted by the White heteroscedasticity test

utilization efficiency because the latter excludes the impact of substitution between energy and other factors.

As we mentioned in Chap. 2, under a market economy, energy economic efficiency is the most appropriate index. Because there are differences in the regional energy resources and transportation networks, there are significant differences in the prices of energy by usage and type. As for the different regions, even if their output is the same (or the returns to scale are unchanged), their position along the production frontier and their relative factor prices are different. Therefore, their best combination of factors is different. The energy utilization efficiency is an important part of the energy economic efficiency, which shows that the marketization process has a significant effect on the differences of the regional economic efficiencies of energy.

7.3 Evolution of Energy Physical Efficiency in the Regional Iron and Steel Sector

7.3.1 Introduction

China is the largest steel producer and consumer in the world. Since 2001, when China stepped into a new period of economic growth, the Chinese steel industry has been rapidly expanding. There has been seven years of continuous growth in the output of steel, and the dramatic growth rate is far more than the growth rate of the economy, as shown in Fig. 7.4. Because of the global economic crisis in 2008, the growth rate of crude steel outputs decreased by 2.4 %, according to the data of NBS (2010). However, due to the macroeconomic regulations and control policies by the Chinese government, large-scale infrastructure construction, and substantial growth in output of the auto industry, the output of crude steel in China in 2009 was higher than that in the previous year by 13.5 %, reaching 5.68 billion tons and accounting for 47 % of the total output of crude steel in the world.

The steel sector is an important fundamental industry in China's economy, as well as the largest consumer of energy. Since 2001, with a sharp growth in total output, the growth in energy consumption by the steel sector is noticeably higher than that for China as a whole. The proportion of energy consumption in the steel sector to the total energy consumption is continually increasing. As Fig. 7.5 shows, based on IEA (2009) and our calculations, China's steel sector consumed 4.78 billion tce in 2007, accounting for 18 % of the total energy consumption in China. Of this amount, coke consumption was 2.58 billion tons, representing 85 % of the total coke consumed in China. The amount of energy conservation in the steel

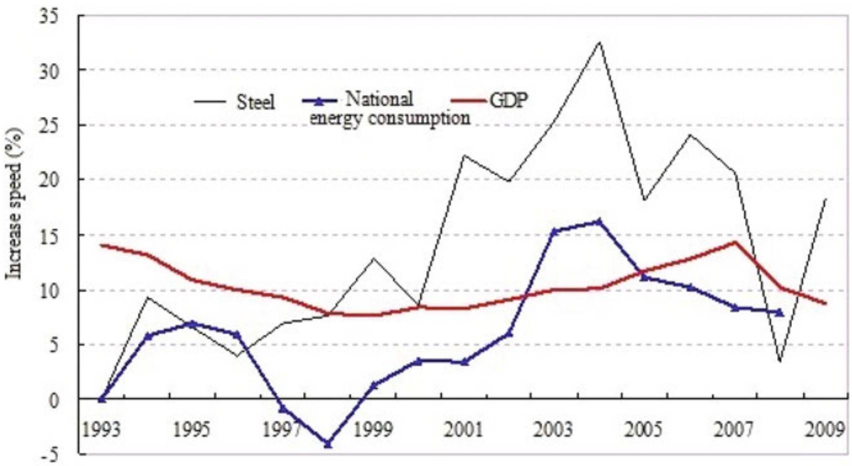

Fig. 7.4 Steel production, energy consumption and the increase in GDP (1979–2009). *Data sources* NBS (2010) and authors' calculations

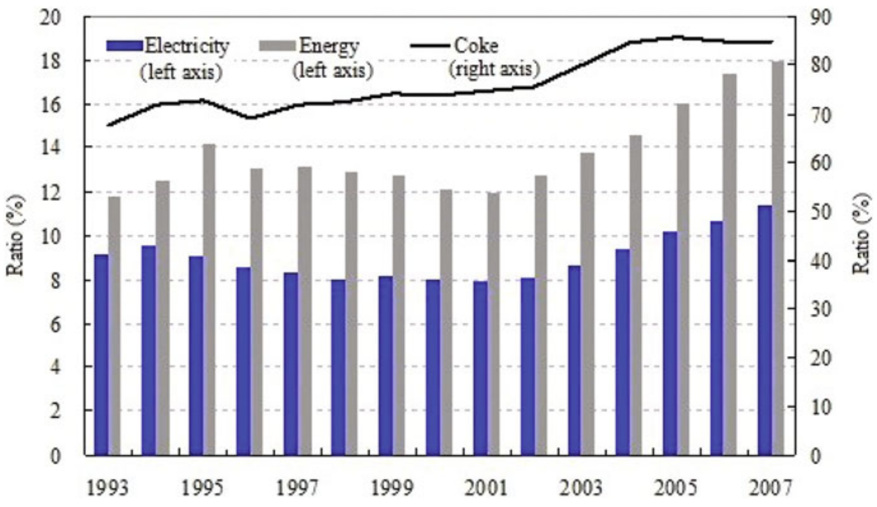

Fig. 7.5 Ratio of steel sector energy consumption to China's total energy consumption (1993–2007). *Data sources* IEA (2009) and authors' calculations

sector has a significant influence on the performance of energy conservation measures in China. The purpose of this section is to analyze the various regions of China in terms of the physical energy efficiency variations in the steel sector.

The Malmquist index is a kind of distance function used to measure productivity. Färe et al. (1985) adopted the dynamic data envelopment analysis (DEA) method to elevate the index from mathematical to quantitative research. The Malmquist index decomposition method (MPI) is suitable to a multi-input and multi-output system, whose mathematical essence is still the multiple objective planning approach. During the actual research, MPI is partially used in the research on economic growth and total factor productivity (Coelli et al. 2005). This section introduces the Malmquist index decomposition method into our research on the regional differences of the efficiency of energy in-kind and its evolution, and it decomposes the energy macro efficiency into two parts—the energy technical progress and the variations of energy technical efficiency. The latter can be used to measure whether the differences in energy efficiency expand or not; that is, whether or not it reflects the catching-up effect. Compared with the Divisia index method, the Malmquist index has the advantage of only needing a small amount of fundamental data and it is an easy and convenient way to deal with the data of secondary energy, such as coke oven gas, waste heat, and so on.

When making a comprehensive comparison of the energy efficiency of the steel sector, we always adopt the practical method, such as the comprehensive energy consumption per ton of steel and the comparable energy consumption per ton of steel. This approach makes a great contribution to comparing and analyzing the energy system of steel enterprises by finding the production process with the lowest energy efficiency and determining the relevant program for adjusting the production structure and improving the technique. However, sometimes it is difficult to reflect or eliminate the effect of the product and energy structures. It is undeniable that the steel enterprises need to consume all types of energy to complete the various production processes (such as sintering, ironmaking, steelmaking, rolling, etc.).

7.3.2 Malmquist Index Decomposition Method

Figure 7.6 shows how to use the panel data to calculate the variations and decompositions of the physical energy efficiency of the steel sector. To simplify our approach, we only introduce the situation of a single-input and single-output system with constant returns to scale.

Suppose there are n regions with the production frontier plane F_t in period t (consisting of the regions with the best energy efficiency in this period). A_t and A_{t+1} have the production status (x_t, y_t) and (x_{t+1}, y_{t+1}) in region A. And x is the energy input, while y is the output of steel. B_t and C_t reflect the relevant frontier plane during the period between t and $t + 1$ when the input is x_t, which means that, in region A, the input is x_t and the output of steel is y_t. Keeping the output constant and referring to the best production efficiency of the frontier plane, the potential input is $x_t^{F,t}$ (if in period t) and $x_t^{F,t+1}$ (if in period $t + 1$), which is less than the actual input and means that there is room to improve the energy efficiency. Similarly, we can explain both B_{t+1} and C_{t+1}.

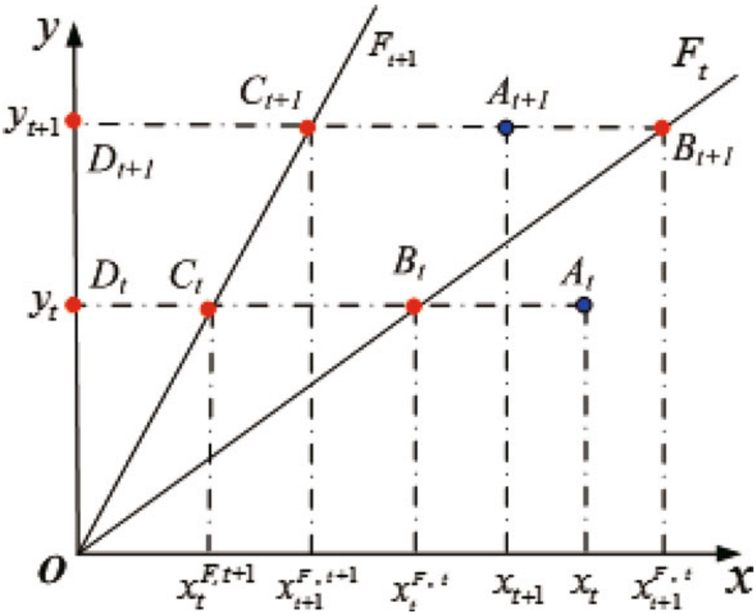

Fig. 7.6 Malmquist index and its decomposition

In region A, the level of the energy physical efficiency of the steel sector in period t is (output/input):

$$e_p = \frac{y_t}{x_t} \tag{7.4}$$

Then, the variation of energy efficiency from period t to period t + 1 can be written as (that is, the Malmquist index):

$$EEC_{t,t+1} = \frac{y_{t+1}/x_{t+1}}{y_t/x_t}. \tag{7.5}$$

The energy technical progress from period t to period t + 1 can be measured through the direction and distance of movement of the frontier plane:

$$\frac{\text{Energy technology level of } t+1 \text{ period}}{\text{Energy technology level of } t \text{ period}} = \frac{OD_t/C_tD_t}{OD_t/B_tD_t} = \frac{y_t\Big/x_t^{F,t+1}}{y_t\Big/x_t^{F,t}} = \frac{x_t^{F,t}}{x_t^{F,t+1}} \tag{7.6}$$

or,

$$\begin{aligned}\frac{\text{Energy technology level of } t+1 \text{ period}}{\text{Energy technology level of } t \text{ period}} &= \frac{OD_{t+1}/C_{t+1}D_{t+1}}{OD_{t+1}/B_{t+1}D_{t+1}} = \frac{y_{t+1}\Big/x_{t+1}^{F,t+1}}{y_{t+1}\Big/x_{t+1}^{F,t}} \\ &= \frac{x_{t+1}^{F,t}}{x_{t+1}^{F,t+1}}\end{aligned} \tag{7.7}$$

This is similar to the ideal indexes by Fisher that take the aforementioned geometric averages as the technological progress measure in empirical research:

$$TC_{t,t+1} = \sqrt{\frac{x_t^{F,t}}{x_t^{F,t+1}} \cdot \frac{x_{t+1}^{F,t}}{x_{t+1}^{F,t+1}}} \tag{7.8}$$

The energy technology level in period t is:

$$\frac{B_tD_t/OD_t}{A_tD_t/OD_t} = \frac{x_t^{F,t}/y_t}{x_t/y_t} = \frac{x_t^{F,t}}{x_t} \tag{7.9}$$

Changing the result of the energy technology level from t to $t+1$ can be represented as follows:

$$\begin{aligned} EC_{t,t+1} &= \frac{\text{Energy technology effiency level of } t+1 \text{ period}}{\text{Energy technology effiency level of } t \text{ period}} = \frac{\frac{x_{t+1}^{F,t+1} \big/ y_{t+1}}{x_{t+1}/y_{t+1}}}{\frac{x_t^{F,t} \big/ y_t}{x_t/y_t}} \\ &= \frac{x_{t+1}^{F,t+1} \Big/ x_{t+1}}{x_t^{F,t} \big/ x_t} \end{aligned} \tag{7.10}$$

According to the geometric relationship in Fig. 7.6:

$$\frac{x_{t+1}^{F,t}}{x_t^{F,t}} = \frac{y_{t+1}}{y_t}, \ \frac{x_{t+1}^{F,t}}{x_{t+1}^{F,t+1}} = \frac{y_{t+1}}{y_t} \tag{7.11}$$

The product of the energy technological progress and energy technological efficiency changes is equal to the change in energy efficiency:

$$\begin{aligned} TC_{t,t+1} \cdot EC_{t,t+1} &= \sqrt{\frac{x_t^{F,t}}{x_t^{F,t+1}} \cdot \frac{x_{t+1}^{F,t}}{x_{t+1}^{F,t+1}}} \cdot \left(\frac{x_{t+1}^{F,t+1}}{x_{t+1}} \Bigg/ \frac{x_t^{F,t}}{x_t} \right) \\ &= \sqrt{\frac{x_{t+1}^{F,t}}{x_t^{F,t}} \cdot \frac{x_{t+1}^{F,t+1}}{x_t^{F,t+1}}} \cdot \frac{x_t}{x_{t+1}} \\ &= \frac{y_{t+1}/x_{t+1}}{y_t/x_t} \\ &= EEC_{t,t+1} \end{aligned} \tag{7.12}$$

The aforementioned formulae show that the changing situation of energy efficiency $EEC_{t,t+1}$ can be divided into two appropriate parts that include the energy technological progress $TC_{t,t+1}$ and energy technological efficiency changes $EC_{t,t+1}$. $TC_{t,t+1}$ reflect the change in the production frontiers and usually $TC_{t,t+1} > 1$ $EC_{t,t+1}$ reveal the changing situation of the difference between the non-frontier districts and frontier districts. If the difference narrows, then they reflect the effects of catching-up, $EC_{t,t+1} > 1$. Here, technological progress and efficiency changes refer to their relationship with energy use (which is partial), and this is completely different than the concept under the framework of total factor productivity.

In most of the empirical research literature using the Malmquist index decomposition method, "frontier" is defined (or implicitly defined) as having the most advanced technology, the most advanced management methods and optimal regional or corporate configuration efficiencies. However, in practice, every company or district does not take an absolutely dominant position at all times. For example, some districts have an efficiency advantage in steel rolling production and some perform better in steel pudding. So we hold the position that the concept of the production frontier has an average meaning and that the companies or districts have the best management as a whole. Even if company A, which is not a leader in its field and not in the frontier, improves its own working process efficiency due to the innovation of technologies, this change may not lead to any changes in the production frontier. The only exception is that this innovation is applied to at least one company in the frontier (or A has already been in the frontier thanks to this kind of technological innovation). Hence, the supposed "technical progress" obtained by using the Malmquist index composition method is, to some degree, meaningless (because it cannot make an accurate assessment of "technical progress"). What should be of concern is the technical efficiency; that is, if the efficiency difference is expanding or narrowing and whether there is a catch-up effect.

As for the multi-inputs and multi-outputs of the steel production system (strictly, the complete multiple production processes), we can determine this by defining and composing the distance function to get $EEC_{t,t+1}$ through linear programming. F_t is the production frontier in the period t:

$$F_t = \{(X_t, Y_t): X_t \,\text{can produce}\, Y_t\} \tag{7.13}$$

where X and Y are the energy inputs and outputs, respectively, of all kinds of processes. And the distance functions for the two periods are defined as:

$$D_t(X_t, Y_t) = \sup\{\theta: (X_t/\theta, Y_t) \in F_t\} = (\inf\{\theta: (\theta X_t, Y_t) \in F_t\})^{-1} \tag{7.14}$$

$$\begin{aligned} D_{t+1}(X_{t+1}, Y_{t+1}) &= \sup\{\theta: (X_{t+1}/\theta, Y_{t+1}) \in F_{t+1}\} \\ &= (\inf\{\theta: (\theta X_{t+1}, Y_{t+1}) \in F_{t+1}\})^{-1} \end{aligned} \tag{7.15}$$

$D_t(X_t, Y_t)$ is the distance between the production point $\alpha_{M_i} d \ln M_i$ and the frontier plane in period t. θ is the proportion by which the X_t can decrease when the Y_t is fixed. $D_t(X_t, Y_t)$ is the maximum proportion by which θ can decrease. Obviously $D_t(X_t, Y_t) \geq 1$. When $D_t(X_t, Y_t) = 1$, it means that X_t cannot decrease any further, so it is located on the frontier.

We then define the distance function in periods t and $t + 1$, respectively, to reflect the technical progress:

$$D_t(X_{t+1}, Y_{t+1}) = \sup\{\theta: (X_{t+1}/\theta, Y_{t+1}) \in F_t\} = (\inf\{\theta: (\theta X_{t+1}, Y_t) \in F_t\})^{-1} \tag{7.16}$$

$$D_{t+1}(X_t, Y_t) = \sup\{\theta: (X_t/\theta, Y_t) \in F_{t+1}\} = (\inf\{\theta: (\theta X_t, Y_t) \in F_{t+1}\})^{-1} \tag{7.17}$$

$D_t(X_{t+1}, Y_{t+1})$ is the maximum proportion by which X_{t+1} can decrease in terms of using the technical progress in period t as a reference and keeping the output Y_{t+1} fixed. $D_{t+1}(X_{t+1}, Y_{t+1})$ is the maximum proportion by which X_t can decrease when in terms of using the technical progress in period t + 1 as a reference and keeping the output Y_t constant. Now, we can decompose the energy macro-efficiency index $EEC_{t,t+1}$, which is as follows:

$$EEI_{t,t+1} = \left(\frac{D_{t+1}(X_t, Y_t)}{D_{t+1}(X_{t+1}, Y_{t+1})} \cdot \frac{D_t(X_t, Y_t)}{D_t(X_{t+1}, Y_{t+1})}\right)^{1/2}$$
$$= \underbrace{\left(\frac{D_{t+1}(X_{t+1}, Y_{t+1})}{D_t(X_{t+1}, Y_{t+1})} \cdot \frac{D_{t+1}(X_t, Y_t)}{D_t(X_t, Y_t)}\right)^{1/2}}_{TC} \cdot \underbrace{\frac{D_t(X_t, Y_t)}{D_{t+1}(X_{t+1}, Y_{t+1})}}_{EC} \tag{7.18}$$

The variation of energy technical progress is:

$$TC_{t,t+1} = \left(\frac{D_{t+1}(X_{t+1}, Y_{t+1})}{D_t(X_{t+1}, Y_{t+1})} \cdot \frac{D_{t+1}(X_t, Y_t)}{D_t(X_t, Y_t)}\right)^{1/2} \tag{7.19}$$

The variation of energy technical efficiency is:

$$EC_{t,t+1} = \frac{D_t(X_t, Y_t)}{D_{t+1}(X_{t+1}, Y_{t+1})} \tag{7.20}$$

If we continually measure the energy efficiency index, technical progress index, and variation index of technical efficiency in n + 1 periods (t = 1, 2,…, n) and combine the indexes over the years, we can get the energy efficiency index $CEEI_0 = \prod_{i=1}^{n} EEI_0^{1+i}$, technical progress index $CTC_0 = \prod_{i=1}^{n} TC_0^{1+i}$ and variation index of technical efficiency $CEI_0 = \prod_{i=1}^{n} EC_0^{1+i}$ in period t + 1, relative to period t. Then, the average growth rate of energy efficiency from t to t + n is $\sqrt[n]{CEEI} - 1$, the average technical progress rate is $\sqrt[n]{CTI} - 1$ and the average variation index of technical efficiency is $\sqrt[n]{CEI} - 1$.

These distance functions can be solved through the DEA method for any region O:

$$\begin{array}{ll} \text{The objective function} & \min \theta \\ \text{The constraints} & \begin{cases} \sum_{i=1}^{n} \lambda_{i,t} X_{i,t} \le \theta X_{o,t} \\ \sum_{i=1}^{n} \lambda_{i,t} Y_{i,t} \ge Y_{o,t} \\ \lambda_{i,t} \ge 0, \quad i = 1, \ldots, n \end{cases} \end{array} \tag{7.21}$$

And the $\lambda_{i,t}$ is the endogenous weight. The optimal value $\theta^* = \frac{1}{D_{o,t}\left(X_{o,t}, Y_{o,t}\right)}$. We can also adopt the DEA method in terms of the slack variable (DEA-SBM) to define the distance function.

It is notable that the Malmquist index usually cannot meet the case of transitivity because of the slack variable (according to the limited empirical research, almost all the studies do not pay attention to this case). Hence, the mathematical theory of the

Malmquist index is accurate (essentially, it is a multi-objective programming model). However, in actual research, there may be many problems; for example, it is sensitive to the data of the decision-making units on the boundary (frontier). This section will attempt to introduce the above method and ideas into our research on energy efficiency. So the conclusions of our empirical research are still preliminary.

7.3.3 Data Sources, Results, and Discussion

7.3.3.1 Data Source and Pre-treatment

This section mainly concentrates on the energy efficiency changes among different regions in China from 1994 to 2003 (the recent yearbooks fail to offer energy data). We use the various energy consumption amounts as the input and the various iron and steel product amounts as the output. Output includes every production process and intermediate output, avoiding any double counting. For instance, if a company produces all the pig iron that it needs by itself, the consumption of the pig iron would be included in that company; however, if a company outsources some of the pig iron to make steel, then the outsourced amount would not be included in that company. All data comes from the *Chinese Steel Industry Fifty Years Data Compilation* (Volumes I, II) and the *China Steel Industry Yearbooks* from 1995 to 2004. Tibet, Ningxia, Qinghai, and Hainan hardly make any iron and steel, so we do not consider these four regions. To avoid large data errors, Shanxi province is also ignored because its iron and steel sector is only involved in the production and export of coal and coke. To maintain the consistency of the statistical data, the Chongqing region is merged with Sichuan province after 1997. For the convenience of computing the average change in the national iron and steel industry on the energy material efficiencies, we consider the entire steel and iron industry as a decision-making unit. This will not influence the results of other decision-making units because the national average level is definitely not at the leading edge of energy efficiency, and this level is more suitable than using the arithmetic average of every province as the national energy efficiency measurement indicator. As a result, we have a total of 26 provinces, municipalities, and autonomous regions and a total of ten years of decision-making data.

The input indicators of the Malmquist index model are the various purchases of energy combined into three categories: Oil–gas–electricity, coal, and coke. The input for the oil–gas–electricity category is obtained by aggregating the consumption of electricity, natural gas, and fuel oil converted on a coal equivalent basis; coal includes fuel coal and coking coal; the coke used as a raw material (reducing agent) in steel production is a separate input indicator. Indicators of the output of the model include the production of various types of steel products: pig iron, crude steel, and finished steel.

7.3.3.2 Results and Discussion

Figure 7.7 presents the national iron and steel sector's physical energy efficiency change index, technology index, and technical efficiency index computed via the Malmquist index decomposition method.

(1) During the 1994–2003 period, the energy efficiency in China's iron and steel sector shows an upward trend, in general, where the national CEEI reaches 1.603 for a total increase of 60.3 % and an average annual increase of 5.4 %. The iron and steel sector's energy efficiency increased 92.4 % for a gap of more than 30 %. This indicates that the energy efficiency rate of increase slows down when considering the energy structure and the steel-output structure. The actual data proves this point: the ratios of pig iron, crude steel, and steel output in China in 1993 were 1:1.02:0.88 while the ratios in 2003 were 1:1.04:1.13. The percentage of the low-energy consuming steel rolling output had a greater weight while the high-energy consuming pig iron output had a relatively lower weight.

(2) China's iron and steel sector's technology index reached 2.183 in 2003, an increase of 118.3 % compared with 1994, for an average annual increase of 9.1 %. The technical efficiency index in 2003 was 0.734, a decrease of 26.6 % compared with 1994, for an average annual decline of 3.4 %. This shows that the energy efficiency gap among different regional iron and steel sectors was wide from 1994 to 2003.

(3) Energy efficiency among all regional iron and steel sectors was significantly enhanced between 1994 and 2003. Fujian, Jiangxi, Gansu, and Jilin improved

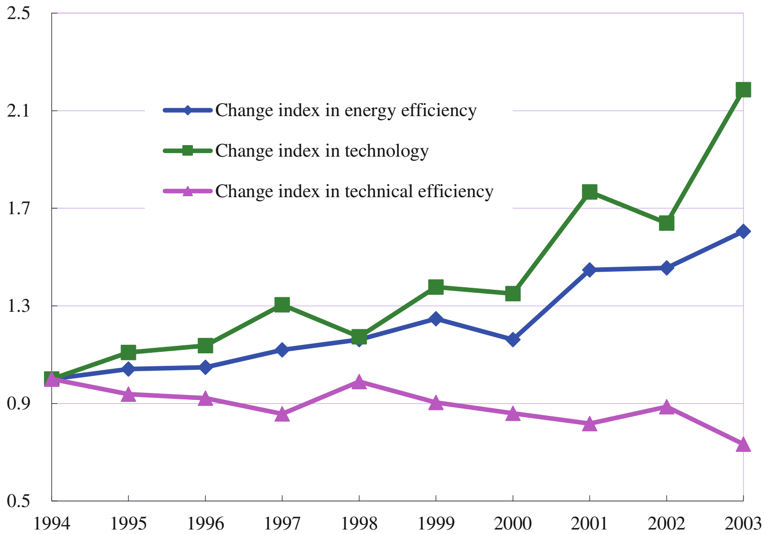

Fig. 7.7 Change in energy efficiency of China's iron and steel sector (1994–2003). *Data source* authors' calculations

the most at more than 150 % while the steel production in these four regions was relatively low. The four state-owned iron and steel production enterprises in Shanghai, Liaoning, Beijing, and Hubei had the lowest energy efficiency increase rate, which was lower than 35 % on average. For Shanghai, it may be due to an already high energy efficiency starting point for the BaoSteel Group and the modest increase in production from 1994 to 2003 (crude steel only increased 30 %, which is much lower than the national increase of 140 %). This shows that the energy efficiency gap between Shanghai and other regions is narrowing rapidly, showing a strong catching-up effect. The situation among Beijing, Hubei, and Shanghai is somewhat similar, where the increase in production is not significant. Liaoning is China's oldest steel-industry base, but its cumulative energy efficiency index (1.287) and technical efficiency improvement index (0.580) are second-last and last, respectively, which may be associated with the dilemma of state-owned corporation reforms.

(4) Though all regional steel and iron industry efficiency rates point upwards overall, they do not keep rising every year. All regions except Shandong province have suffered a decline in energy efficiency in one or more years, including Anhui province, which experienced serious declines in 1996 and 2002. The reasons may lie in the data quality or the suitability of using the Malmquist model itself (multiple goal programming). It may also be the substantial fall in the coal price in some years, resulting in a low enthusiasm for corporate energy savings, as well as for substituting energy in the production of other elements such as iron ore.

7.4 Summary

In this chapter, we used the Theil index method to analyze the regional energy macro efficiency (per unit of GDP in terms of energy consumption) difference in 2006. The result shows that this difference of almost 80 % was caused by structural differences among the three main industries. For the high (per unit of GDP) energy consumption regions, they should concentrate on adjusting and optimizing their industrial structures (especially the three main industrial structures), in addition to technical improvements, which should be highly valued. The degree of the energy-resource dependence on foreign trade and the degree of marketing are important factors affecting the regional differences in the energy consumption per unit of GDP and in the per unit industrial value added (the latter factor's explanatory degree is larger). The regression results indicate that the marketing degree increases per unit of production while the energy consumption per unit of GDP and per unit of industrial value added declines about 1.9 and 2.6 %, respectively. In addition, when the dependence on foreign trade rises by 1 %, the energy consumption per unit of GDP and per unit of industrial value added decline by approximately 0.1 %.

We also applied DEA to our research on China's regional industrial sectors' energy utilization efficiency in 2006. The results illustrate the obvious correlation between the regional energy utilization efficiency and the energy macro efficiency. However, the regional differences declined enormously. The degrees of energy resource endowment and marketing also contribute toward the differences in regional energy utilization efficiencies, but their explanatory degrees are lower than that for the differences in macro efficiency. This is mainly because energy utilization efficiency replaces or reduces the influence of the substitution of energy with capital and labor.

In a horizontal comparison of regional energy efficiencies, there will be a bias error if one only uses the energy consumption index per unit of GDP. Moreover, any energy policy based on this index may not function very well either.

This chapter also uses the Malmquist index decomposition method to study the different evolutionary characteristics of energy efficiency in China's regional iron and steel sectors. The outcome shows that the energy efficiency in the iron and steel sector rose quickly in all regions from 1994 to 2003 while the gap among the regions widened. Because the Malmquist index method is essentially used to evaluate multiple objective programs, it does not deal very well with the slack variable problem (though the DEA–SBM model is used). Moreover, the data is particularly sensitive to the decision-making units that determine the boundary (frontier), so improvement of this method is still needed in the future.

References

Alcantara V, Duro JA (2004) Inequality of energy intensities across OECD countries: a note. Energy Policy 32(11):1257–1260

Coelli TJ, Rao DSP, O'Donnell CJ et al (2005) An introduction to efficiency and productivity analysis, 2nd edn. Springer Science & Business Media, New York

Dalton H (1920) The measurement of the inequality of incomes. Econ J 30(119):348–361

Department of Energy of National Bureau of Statistics, Department of Comprehensive Statistics of National Energy Administration (2009) China energy statistical yearbook 2008. China Statistics Press, Beijing

Department of Industry and Transport Statistics of National Bureau of Statistics (2007) China energy statistical yearbook 2007. China Statistics Press, Beijing

Department of Industry and Transport Statistics of National Bureau of Statistics, Bureau of Energy of National Development and Reform Commission (2007) China energy statistical yearbook 2006. China Statistics Press, Beijing

Fan G, Wang XL, Zhu HP (2006) China marketization index–annual report of provinces' relative marketization process 2006. Institute of National Economic Research of China's Economic Reform Research Foundation, Beijing

Färe R, Grosskopf S, Lovell CAK (1985) The measurements of efficiency of production (studies in productivity analysis). Kluwer-Nijhoff Publishing, Boston

Gini C (1921) Measurement of inequality of incomes. Econ J 31(121):124–126

IEA (2009) World energy statistics and balances (2009 edition). International Energy Agency (IEA), Paris

Liao H (2008) Study on econometric model of energy efficiency and its application. Dissertation, Chinese Academy of Sciences

National Bureau of Statistics (2007) China statistical yearbook 2007. China Statistics Press, Beijing

National Bureau of Statistics (2010) National statistics database

Theil H (1967) Economics and information theory. Amsterdam

Chapter 8
Energy Efficiency in Developed Countries and Its Implications for China

Improving energy efficiency is a cost-effective and important approach for mitigating climate change and guaranteeing energy security. In the past, several developed countries and regions, including Japan and the European Union (EU), have attached great importance to the improvement of energy efficiency, and they have developed relatively complete mechanisms. Over the past 35 years (1974–2009), the GDP of IEA member states has increased 144 %, whereas the energy intensity has fallen by 41 %, which can be attributed to a great amount of improvement in energy efficiency. In this chapter, we mainly compare the energy efficiency policies and innovative experiences of Japan, the EU and the United States (US) and focus on four problems, as outlined below:

- What tax and fiscal policy measures did the developed countries adopt?
- What policies did the developed countries implement to promote the research and development of the energy conservation technology?
- What administrative policies did governments in the developed countries implement to facilitate the improvement of their domestic energy efficiency levels?
- What effects do the energy efficiency policies of the developed countries have on China?

8.1 International Comparison of Legal Mechanisms

In general, developed nations have enacted relevant laws in terms of the basic and legal grounds on which to boost energy efficiency. Japan issued the "Energy Conservation Law," the US passed the "American Clean Energy and Security Act," and the EU has drawn up legislation for its member states. In addition, governments have established special departments responsible for energy efficiency and energy conversation. For example, the Office of Energy Efficiency and Renewable Energy

Y.-M. Wei and H. Liao, *Energy Economics: Energy Efficiency in China*,
DOI 10.1007/978-3-319-44631-8_8

under the US Department of Energy takes responsibility for energy efficiency, but in Japan, such matters are handled by the Ministry of Economy, Trade and Industry.

8.1.1 Laws and Regulations

Owing to its energy system, Japan has been among the leading countries in energy efficiency, but it still focuses on reducing its energy consumption per unit of GDP on the basis of a low energy intensity. Over the past 30 years of development, Japan has formed a complete legal system by combining the government, energy industry, and the people. Its Energy Conservation Law acts as the cornerstone of its energy policy, which includes the energy management of the industrial, commercial, and transportation sectors. Moreover, it includes the energy efficiency standards for cars, households, commercial buildings, and so on. After the law was passed in 1979, there have been five amendments: in 1993, 1998, 2002, 2005, and 2008. By periodically passing and improving its laws, Japan has built a sound energy consumption code, whose safeguards have embodied the legalization and normalization processes.

Because of global climate change and high energy prices, the US government has significantly increased its energy-saving intervention efforts. Congress frequently passes energy-related laws and regulations. According to the *National Energy Policy Act* passed in 2005, the US will cut taxes ($14.6 billion) for all US energy enterprises within 10 years to encourage these enterprises (including oil, gas, coal, and electric power) to take appropriate measures on energy conversation and environmental protection. The *Federal Energy Legislation* passed in 2007 drew up more detailed plans for automobile fuel economy standards, equipment energy standards, industrial standards, regional energy savings, and so on. Furthermore, although the US did not sign the *Kyoto Protocol*, several state governments have proposed specific targets for saving energy and reducing emissions. In 2006, the state of California passed the *Global Warming Solutions Act*, which was the first cap-scheme bill for greenhouse gases in the country. In 2007, the US Congress passed the *United States Climate Security Act* to cut greenhouse gas emissions and maintain strong economic growth. So far, these bills have played an important role in various forms and the states have pursued various energy-saving methods. A $168 billion economic-stimulus bill was enacted by the US in February 2009. This bill almost included all of the economic aspects and new energy policies, as clean sources of power and energy conservation were the key points of the bill. The new energy policies of this bill were universally recognized by American society. The *American Clean Energy and Security Act* was designed to reduce greenhouse gas emissions in the US and was narrowly passed by the House of Representatives in July 2009. Title 2 of this Act is about energy efficiency, including some specific items about architectural lighting, the transportation industry, and household energy use.

The EU and its member states share sovereignty in the active political regime within the bloc, but the member states maintain their own sovereignty regarding tax and energy policy. While the EU has issued some directives to its member states, it has also used its power to introduce a series of incentives for the improvement of energy efficiency. In terms of an energy-savings policy, the EU aims to develop a uniform, official, and competitive energy market. The organization has always pursued a common policy and made a concerted effort to reach a series of grand efficiency targets. In March 2006, the EU published its *EU Energy Policy Green Paper*, which included six priority areas for development and 12 specific policy recommendations about energy efficiency and low-carbon technologies. In December 2006, the European Parliament passed the *EU Energy Strategy*, which demanded that its members improve their efficiency by 20 % and reduce their carbon emissions by 30 %. At a summit in March 2007, the EU adopted a series of measures: (1) the EU states would individually promise that they would decrease their greenhouse gas emissions 20 % by 2020, (2) renewable energy would represent 20 % of the EU's total energy consumption, and (3) compared with the baseline scenario, the consumption of primary energy would decrease 20 % by 2020. In 2006, the EU proposed its *Intelligent Energy European Plan* to support its six priority areas for energy efficiency, representing approximately 45 million euros from 2007 to 2013. The EU also formulated its *Energy Efficiency Action Plan* to implement the measures. In January 2007, the European Commission submitted its *Energy Policy Proposals* to the European Parliament and the Council. It analyzed the present status of energy efficiency and suggested an integrated framework of EU energy policies and targets. In addition, the Commission specified some sectors that should improve their energy efficiency, including the transportation sector's energy-savings measures, the minimum thresholds of the energy efficiencies of energy-saving equipment, improvement in the energy requirements of buildings, and so on. It was also pointed out that the full benefits of efficiency should be realized by the markets and supported by public energy services (Foreign Affairs Department NDRC 2005).

8.1.2 Energy Conservation Mechanisms

One of the reasons for Japan's remarkable outcome in terms of energy efficiency is its explicit divisions of labor and management system, which can be divided into three tiers. The first tier is the energy-saving lead agency, which predominantly consists of the Ministry of Economy, Trade and Industry (METI) and local bureaus of economy and industry that have the main responsibility for the energy-saving management of various industries. These state organizations include the Ministry of the Environment (MOSTE), the Ministry of Land Infrastructure and Transport (MLIT), the Ministry of Education, Culture, Sports, Science and Technology (MEXT), and so forth. The second tier includes the energy-saving professional institutes, such as the Energy Conservation Center (ECCJ), which is in charge of the promotion and implementation of energy conservation, and the New Energy Development Organization, which is responsible for the organization, administration, extension, and application of projects from the research to development stages. Finally, the third tier comprises the energy-saving designated factories (key energy-consuming units) and the producers and dealers of energy-saving products who ensure the implementation of a series of energy-saving policies. This manner of assigning responsibilities and duties substantially contributes to a positive situation, whereby every department expedites the operation of energy-saving enterprises with effective cooperation. METI takes charge of developing and implementing the energy-saving policies related to industry, construction, transportation, product standards, and so on. MLIT assists in drawing-up the standards for construction and cars. It is also responsible for the energy efficiency management of the transport companies. The Japanese prefectures preside over the supervision and management of the buildings' energy efficiency. The Office of Resources and the Environment oversees the management of energy savings and it has various offices for energy production, power supply, energy savings, new energy sources, and so on. What is different about the management system in China is that METI directs the subordinate prefectures to perform in a centralized mode that ensures that its mandates will be implemented in a timely and effective manner (Yang and Yang 2008).

The management style in the US is a national focus on energy issues. The Office of Energy Efficiency and Renewable Energy is subordinate to the Department of Energy and takes charge of managing the energy and renewable energy matters. There are more than 500 staff members with a budget approximating $1.3 billion. Their functions are to improve energy efficiency, research clean and reliable energy technologies, improve residential energy services, and so on. At the same time, Energy Analysis and Diagnostic Center (EADC) was founded to help small and medium-sized manufacturing enterprises to support services related to energy auditing, evaluate these enterprises, and make recommendations. Since its establishment, EADC has helped enterprises improve their energy efficiency and has had a beneficial effect on pollution abatement and increasing total productivity. Regarding the economy and the technical development of energy, many scientific institutes have been set up in the US, such as the National Renewable Energy Laboratory and the Lawrence Berkeley National Laboratory. They organize and implement R&D activities, as well as key projects that provide a roadmap for energy-saving development strategies.

The EU primarily enforces its policies in the form of directives, which are formally implemented after its member states enforce the laws domestically. At present, the relevant directives of energy conservation mainly include the household appliances standardized identifier directives (2002), the buildings' energy efficiency directives (2002), the combined heat and power (CHP) directives (2004), the energy-related products within the framework of the eco-design directives (2005), the improvement of energy efficiency and the energy service directives (2006), and so on (Shi 2009). In summary, these directives have three aspects. First, they aim to set compulsory policy goals for its member states or enterprises. Every member state must reduce its total annual energy consumption by 1 % after 2008 (compared with the initial amount), and simultaneously, the power generation produced by

CHP should represent at least 18 % of the total amount. Second, they aim to set not only unified but also regulated criteria for energy efficiency and the identified energy systems by setting minimum energy performance standards (MEPS) for energy-consuming devices (including household appliances), detailed regulations for the standardized dynamic adjustment mechanisms, and minimum energy efficiency standards for new and renovated buildings, as well as implementing a building energy efficiency certificate system in the construction, sale, and leasing processes for housing. Third, the directives propose the implementation of specific policies. Every member state must create and issue a *National Energy Efficiency Action Plan*. Moreover, they must set energy-saving goals for the supply, transmission, and distribution of energy by the various companies and financially support the energy-service companies, including the small and medium-sized enterprises who invest in energy efficiency. In 2009, the EU Committee issued a directive entitled *Establishing a Framework for the Setting of Eco-design Requirements for Energy-related Products* (2009/125/EC) (ErP for short), which was adapted from EuP (2005/32/EC). This directive expanded the number of energy-consuming products of the previous EuP, made stricter energy efficiency standards, and definitely limited other countries who wanted to export their products to the EU.

8.2 International Comparison of Fiscal Policy

Tax and fiscal policies are the main tool for governments to promote energy efficiency. These policies include tax credits, tax rebates, preferential taxes, concessional loans, financial subsidies, accelerated depreciation, and so on. For fossil fuels, countries will impose higher resource-use taxes, which are designed to reflect the cost of the impact on the environment (Price et al. 2005). Figure 8.1 shows the relation between the national unleaded gasoline taxes and gasoline prices (IEA 2010a).

8.2.1 Japan

As for tax and fiscal policies, the Japanese government has given subsidies for the energy conservation of enterprises, buildings, and transportation. These subsidies are intended to advance the spread of energy-saving technologies and equipment.

As to subsidizing energy conservation, the Japanese government provides financial subsidies for the enterprises' energy-saving projects and encourages enterprises to buy highly efficient equipment and to take measures regarding energy-efficient technological renovations. Based on the expected benefits of energy conservation projects and their demonstrative significance, Japan's energy-saving projects are divided into "general projects" and "large-scale projects." The

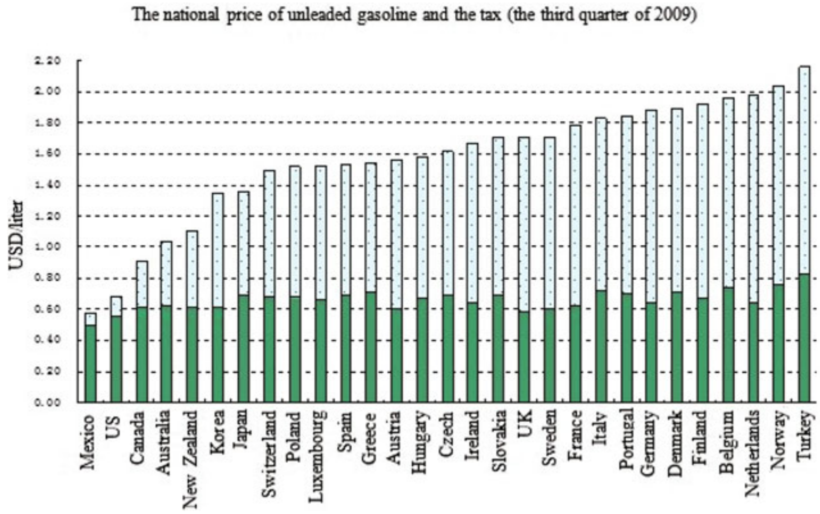

Fig. 8.1 The national price of unleaded gasoline and associated taxes (third quarter of 2009). *Data source* IEA (2010a)

government will allocate one-third of its investment towards general projects, where the total sum will not exceed 0.5 billion yen. Large-scale projects will get up to one-third in subsidies, where the total sum will not exceed 1.5 billion yen. Large-scale projects that include more than one enterprise will get one-half of the total investment, where the total sum will not exceed 1.5 billion yen. If the renovated buildings can reduce their consumption of energy by more than 15 %, they will get an allowance up to one-third of the investment while the existing projects will get the same allowance if they reduce their energy consumption by more than 25 % compared with their average consumption over the last three years. In addition, investment related to the buildings' energy management system will get the same subsidy. What needs to be clearly explained is that the building owners will get the allowance only if they submit reports of the individual building's energy consumption and conservation measures for the three previous years.

With regard to the preferential tax policy, enterprises are going to buy the equipment that can save energy according to the assigned specifications. Any enterprise that puts the equipment to use within one year will have their taxes reduced by 7 % of the cost of the equipment or be eligible to receive a special depreciation rate of 30 % of the cost of the equipment, which is based on the normal depreciation rate. In addition, when leasing the energy-saving equipment, there is accelerated depreciation or preferential tax breaks in accordance with the provisions of the *Tax Special Measures Law*. The policy in traffic reduces the tax rate for environment-friendly cars while increasing the rate for high-pollution cars, and this rate is adjusted every two years. The cars that are up to standard will be assigned a reduced tax on the basis of different levels of gas consumption: the cars that consume 10 % less than that in 2010 will have their tax reduced by 25 % while the cars that consume 20 % less than that in 2010 will have their tax reduced by 50 %. In addition to the cars of a special type and buses, the cars older than eleven years and based on diesel fuel will have their tax increased by about 10 % more than the normal tax, and the same tax rate will apply to the cars consuming gasoline and older than thirteen years. As to automobiles whose fuel is a mixture, the government will allow half of the price difference compared with ordinary cars (Shang 2006).

Japan adopted the notions of low-interest loans and third-party financing to solve the difficult problem of funding energy conservation. To encourage enterprises to invest in energy-saving equipment, the Development Bank of Japan and the Okinawa Public Treasury have specifically provided low-interest loans that allow enterprises to purchase the specified directory's energy-saving equipment. SMEs can apply for low-interest loans to invest in energy-saving equipment promotions; applications can be made to the SME Finance Corporation and National Finance Corporation. In addition to third-party financing, the Japan Development Bank, as a government subsidiary financial institution and in cooperation with the Japan Intelligent Energy Company, jointly set up an energy bank in June 2007, whereby third-party financing would be used to improve energy efficiency and CO_2 emissions. The Energy Bank was officially launched on August 1, 2007 and is expected to have approximately 150 billion yen ($120 million) in its funds in the first three years to help provide energy-efficient equipment (Kasahara et al. 2007).

In addition to the above fiscal and financing policies and in accordance with the provisions of the *Energy Conservation Law*, there are also related penalty policies that are designed to punish enterprises and corporations that perform poorly. For specified primary energy management factories in the industrial sector, they will be disciplined if they fail to submit reports on a timely basis, if their utilization of energy or energy conservation efforts is insufficient, and if they fail to amend their practices after being advised by government officials. The businesses that are exposed and subsequently do not make improvements will be subject to a fine of one million yen. The same process and fines apply to the designated special transport companies in the transportation sector. Furthermore, if the chief officers of any company continue to sell substandard products after being warned by the appropriate government ministers, they may be exposed and punished, and the company may be fined up 100 million yen (International Department of National Development and Reform Commission Training Center 2009).

8.2.2 United States

There are two kinds of funds for saving energy and reducing emissions in the United States. One is the fiscal budget and the other is charitable foundations. For example, for the charitable foundation, the main funding source is from 2 to 3 % of the electricity price. There are 21 states setting up similar charitable foundations in the country, which is in the charge of the Public Utilities Commission (PUC). Departments can apply and use it to carry out energy-saving activities, which reflect the principles of the people and provides services to the people.

There are three financial incentives: cash compensation for energy-saving products, reduction or remission of taxes, and mortgages.

Cash compensation: Most states carry out “Energy Subsidy Projects.” If the power consumption in 2008 is 20 % lower than that in 2007, then 20 % of the electricity bills in 2007 will be returned. So by renewing the energy-efficient appliances, people could receive subsidies from the government. As another example, the government of Diamond Bar, California, encouraged its citizens to take the bus, and if they did so, they would get a subsidy ($80 per month). This government spent $10 million on marketing battery cars, hybrid electric vehicles, and natural gas vehicles to promote energy conservation and reduce pollution, which represents production related to subcontracts by the best automobile companies.

Tax breaks: For example, the California agency responsible for setting the minimum energy efficiency standards for civil construction will reduce the cost equivalent to a 75 cents tax per square foot, accounting for approximately 2 % of the construction costs. In addition, this rebate is also reflected in the financial incentive’s “classification mechanism.” The IECC standards are based on energy-efficient new residential energy conservation measures that were put in place as early as the beginning of this century, and more than 30 % and more than 50 % of new buildings qualified for tax relief of $1000 and $5000, respectively. Moreover, there are many financial incentives for efficient energy-consuming building equipment and a variety of energy-saving equipment, according to the newly enacted energy efficiency indicators, with tax cuts of 10 and 20 %, respectively (Li 2008).

Mortgages: The *U.S. Energy Policy Act of 2005* provides a total of $10 billion of preferential loans for energy-efficient and renewable energy projects. Project approval is by the US Department of Energy, which is responsible for the selection criteria, including the potential for energy savings and emission reductions, the prospects for commercialization, the impact on consumers, project risk, financial risk, and owner solvency. The energy-saving technology and the key supports for the renewable energy sector includes the following: advanced electric power transmission and distribution technology, advanced electricity reservoir storage technology, alternative automotive technology, efficient energy technologies, efficient energy-saving technologies and equipment for buildings, geothermal technology, network and intermittent technical hydrogen fuel cell technology, industrial energy-saving technologies, clean coal power generation equipment, carbon capture technology, advanced coal gasification technology, tidal energy, wind energy, and solar energy utilization technology. Some institutional lenders also offer an “Energy Star” mortgage, whereby people who purchase Energy Star-certified buildings can apply for mortgage loans from these institutions. In addition, these lending institutions take such measures as cash rebates and low-interest loans to encourage people to purchase Energy Star-certified residential buildings (Zhai et al. 2003).

8.2.3 European Union

To support the relatively backward new members in terms of energy savings, the EU, in its policy framework, uses structural and cohesion funds and offers subsidies to energy-saving programs, including support for the start of an energy service industry, subsidizing energy-saving programs for construction, and supporting and establishing energy-saving information and communication networks via the European Investment Bank (EIB), the European Bank for Reconstruction and Development (EBRD), and so on. The Global Energy Efficiency and Renewable Energy Fund (GEEREF) was established in October 2006 by the EU Committee and it is used to adjust private investments in energy efficiency and renewable energy and to promote, develop, and extend environment-friendly technological transfers. In the first four years, the fund was 80 million euros over the initial four years and the initial capital was expected to mobilize the public and private interests to invest another 150–200 million euros, which means that it could generate nearly one billion euros to support global energy efficiency and renewable energy programs.

In the aspects of financial support and according to the different types of projects, namely, the basic, industrial, and experimental research, the funds offered by the EU can approximately account for 100, 50, and 25 %, respectively, for the small and medium-sized enterprises, cooperative research and development, and easily dispersed industrial study programs in which the proportional threshold of financial support is rising. Furthermore, financial subsidies are offered to the enterprises conducting energy-saving technical training, accounting for 50 % of the relevant training fees in the large-sized enterprises and 70 % in the small and medium-sized enterprises, and these subsidies are enhanced by another 10 % for the enterprises located in the relatively backward districts.

The issues of tax incentives and policy are decided by the EU members and they must inevitably reach an agreement. Recently, the EU has gradually shown greater strength in its negotiations on various aspects of the energy conservation tax. In 2007, the Committee issued submissions to the public consultation, "Green Book," in terms of indirect tax reform, conducted a cost–benefit analysis of using tax reductions to encourage energy conservation, and appealed to its member states to agree to lower the value-added tax rate for energy products and services. In 2008, the Committee re-examined its energy and tax directives (2003) to enhance the relevance and coordination of its energy use and tax structures and to combine its energy and environmental conservation targets better. In the aspect of transportation tax, the Committee urged the EU Council to adopt its legislative proposals about the taxation of CO_2 emissions and expected the EU member states to add relevant content to the tax reforms. At the same time, to narrow the gap among its member states by reducing the "Traveling by Trailer" and to enhance energy efficiency, the Committee proposed specific suggestions related to the commercial diesel fuel tax arrangement.

In terms of government procurement, the EU actively supports "green" procurement activities by the public, claiming that the contracts of green public procurement should include the terms of environmental protection and step-up efforts to reform the energy-saving product technologies and services. Due to the government procurement accounting standard, which is supposed to represent 16 % of GDP, the EU promotes and supports the markets of energy-saving products and services so as to accelerate their distribution and boost the confidence of markets to purchase products that conserve energy. In terms of promoting energy conservation, the EU invested an additional 3.6 million euros to launch its program entitled “EU Sustainable Energy in 2005–2008.” At the same time, it also utilized various kinds of public media platforms in the hopes of publicizing and increasing the public’s awareness of saving energy.

8.3 International Comparison of R&D Policy

After the first world oil crisis, the developed countries established the International Energy Agency (IEA) to jointly confront the security of the global energy supply. As shown in Fig. 8.2 and according to the IEA (2010b), the government budget for energy technology research, development, and demonstration (RD&D) in the countries that participated in the IEA witnessed a rapid increase, rising to $19.1 billion in 1981. Thereafter, following the decline in energy prices, RD&D also declined, slipping to $8.9 billion in 1997. However, in recent years, with the global energy prices soaring and climatic conditions deteriorating, the RD&D budget has experienced another period of tremendous growth, reaching $29.4 billion in 2009 (but only returning to the 1981 level, according to PPP).

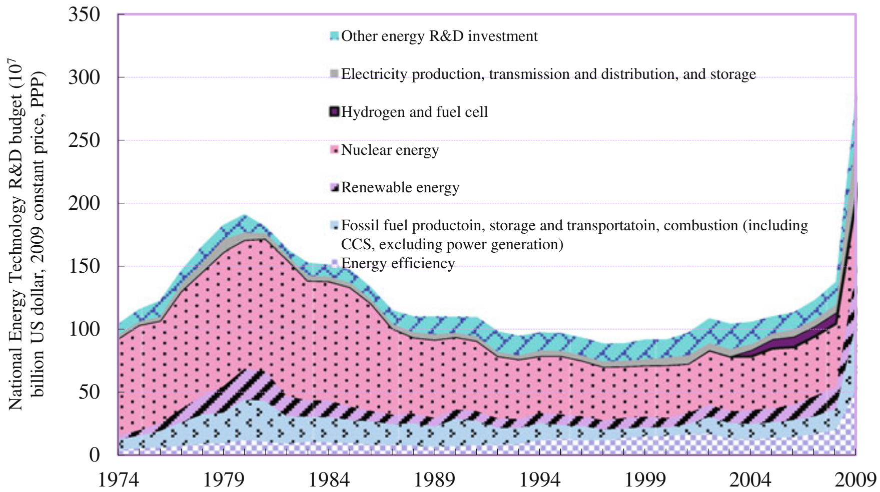

Fig. 8.2 The IEA National Energy Technology R&D and promotional budget (1974–2009). *Data source* IEA (2010b)

8.3.1 Japan

Japan is one of the countries with the highest energy technology investments in the world. Its energy R&D budget to GDP ratio is much higher than that of other developed countries. In 2006, the New Energy and Industrial Technology Development Organization (NEDO) fund for energy technology research and development amounted to 130.6 billion yen. This fund supported the research and development of energy-saving technology totaling 33.4 billion yen, which mainly focused on the advancement of industrial technology research and industrial energy-saving technologies, use of new energy technology, specific projects including the development of energy-saving technology strategies, next-generation transportation vehicles, ultra-efficient natural gas cogeneration projects, and industrial and efficient energy technologies that promoted energy-saving measures. NEDO R&D projects also supported the advancement of energy-saving technologies by fully subsidizing basic research and feasibility studies, providing capital subsidies up to two-thirds of the cost of practical development projects and up to one-half of the cost of projects at the demonstration and promotional stages. The total amount of the enterprises' energy technology R&D subsidies reached 25.975 billion yen in 2007. In 2006, the Japanese government actively promoted the "New National Energy Strategies" and the "Foundation Energy Plan," both of which devised the Japanese strategies of energy-saving technology, specified the issues that were likely to be solved through such technology, and recommended definitive roadmaps for developing the technology to tackle these problems. To be more specific, the energy-saving strategies also categorized and analyzed the commercial development of the following energy technological features in the future: (1) the improvement of overall energy efficiency, (2) the diversity of fuels utilized by the transportation authorities, (3) the development, promotion, and extension of new energy sources, (4) nuclear power and its energy security, and (5) the supply, security, and utilization of clean and efficient fossil fuels.

8.3.2 United States

Americans spent most of their budget allocations for energy conservation on technology research and development, including the "Advanced Energy Plan," "American Competitiveness Initiative," "Clean-coal Generation Plan," and so on. In 2008, the "Advanced Energy Plan" investment was $2.7 billion or 26 % higher than the budget in 2007. It focused on supporting biomass energy, hydrogen energy, solar energy, clean coal generation technology, nuclear energy, etc. As to the "American Competitiveness Initiative," there was an increase of $0.3 billion in 2008 (to $4.4 billion) compared with the budget in 2007. It mainly supported the development of advanced energy technology consisting of $176 million for automobile conservation technology, $148 million for solar projects, $213 million for hydrogen energy and fuel cell development, and $0.4 million for wind-power projects. Clean coal generation plans were made for a 10-year period starting in 2002. The National Energy Technology Laboratory would implement the plans by combining government involvement with the enterprises. The alliance built advanced electrical power plants such as IGCC, coal gasification and liquefied natural gas projects, heat and power cogeneration systems, and so on. In addition, the Energy Efficiency and Renewable Energy Bureau in the DOE was allocated funds amounting to $1.2 billion to support basic energy sciences programs (Tassey 1998).

To facilitate the commercialization of energy-efficient technology, the Energy Department set up a commercial fund of $720 million in October 2008 for its three affiliated labs: Lawrence Berkeley Laboratory ($400 million), Oak Ridge National Laboratory ($250 million), and San Diego National Laboratory ($70 million). These three national laboratories would then utilize their funds to prompt the commercialization of clean energy and energy-efficient technology.

The US focused on accelerating R&D and application of advanced energy technology. In 2009, the total amount of investment in this area had reached $9 billion. The authorities mainly supported climate change, energy supply, and energy savings; they invested $3 billion on the research and development of key technologies. The institutions included the affiliated labs of the US Department of Energy (DOE), National Aeronautic Space Administration (NASA), National Institute of Standards and Technology (NIST), and so on. The funds would be used in various forms, such as the allocations of money by the government and through cooperation with the corporations. The tax policy for the plug-in electric vehicles (PEV) could cost $2 billion in total. To support the manufacturing facilities that are associated with clean energy, setting up new tax-return mechanisms is a political method, anticipated to cost $1.6 billion. Finally, the privileged loans for these initiatives, which are conducive to reducing greenhouse gas emissions, could amount to $2.4 billion (International Department of National Development and Reform Commission Training Center 2009).

8.3.3 European Union

The main measure in the EU is to encourage the R&D of energy savings. That is, to encourage the R&D of the key areas and technologies and demonstration projects by actively supporting the bidding and contract management systems. In the seventh iteration of the EU's research and development program during the 2007–2013 period, the investment budget of the EU in the areas of energy technology stood at 4.7 billion euros. Among these areas, energy efficiency and savings were the main areas of support. Other areas of support included the research network project, joint technology development project, coal and steel research, and the Intelligent Energy Project (IEE). The energy technologies strategic planning program was enacted by the EU in 2009, whereupon it would strengthen the integration of R&D networks and increase the dynamics of funding support. The EU's 7th Framework R&D program (2007–2013) was enacted in December 2006. Its general budget was 50 billion euros of which 2.35 billion euros was allocated for energy and the environment (including climate change), including hydrogen fuel cells, renewable energy generation, production, heating, and cooling, zero-emission power plants that capture and store CO_2, clean coal technology, energy network construction, and energy efficiency, savings, and policy. In terms of energy efficiency and energy savings, the specific areas included industrial energy use during the production process, efficient multi-generational technologies, integration of renewable energy and energy efficiency, and the promotion of energy-efficient technologies (Ma et al. 2006).

8.4 Other Policies to Promote Energy Efficiency

In addition to using legal, fiscal, and tax policies to promote energy efficiency and technology R&D, the governments also support educational awareness programs that encourage people to choose products with a high energy efficiency rating (EER) and develop good habits when consuming energy.

8.4.1 Japan

The Japanese government attaches great importance to promoting energy conservation education. Apart from establishing Energy Saving Day (first day of every month) and Energy Saving Month (February of every year) to popularize and promote energy-saving technology domestically, it hosts various publicity events and educational activities and also sets aside July 1 and December 1 as Energy Saving Inspection Days for assessing energy-saving activities and living habits. The people's energy-saving activities have been from "point to plane," meaning from the level of the single household to a region's energy conservation measures. Supported by the government, some places have set up an "Energy Saving Activity Promotion Association (ESAPA)," which is made up of local government officials, energy-saving experts, representatives of the local residents, and business people whose aim is to study and set regional energy-saving goals to carry out the plans so that the regional energy-saving efficiency surpasses that of individual enterprises or households. The ESAPA often hosts energy-saving lectures and activities, such as establishing a "No Car Day," shutting off the lights in their buildings at the same time and promoting wind energy, solar energy, and other clean energies. The ESAPA also assigns instructors to do some household training. These professional instructors can quickly find sources of energy waste in a household's daily activities and propose definitive energy-saving suggestions. Saving energy and reducing electric power bills are very popular activities among households. Furthermore, the government has taken the lead to conserve energy. In June 2006, it launched an activity called "Energy-saving Clothes." The cabinet members wore energy-saving clothes and all of the ministers were simply dressed and without ties. Moreover, they demanded that the civil servants take off their restricted suits and ties and, in contrast, wear short-sleeved shirts and simultaneously set the buildings' temperature at 28 °C. To encourage and inspire the country's enterprises to continue to innovate, the government holds an annual ceremony every February to award the energy production and consumption units, as well as the energy-saving manufacturers and vendors who have excellent records of energy conservation. The annual number of energy-saving prizes are as follows: 3 Minister of Economy and Industry awards, 5 Office of Energy Resources awards, 15 Local Director of the Economy and Industry Bureau awards, and 33 President of Energy Saving Centre awards (Wang and Chu 2007).

8.4.2 United States

To reduce poverty and enhance the energy utilization efficiency of low-income families, the US Government provides energy subsidies. The Energy Department started a "Weatherization Assistance Program" and has invested \$140.3 million since 2006 to help low-income families enhance their level of energy efficiency and lighten the burden of energy expenditures. As predicted, it reduced annual family expenditures by \$358 on average during the lifespan of the program, and every dollar invested earned \$1.53 in energy-saving benefits and definitely included extra benefits such as enhancements in housing comfort levels and higher values in housing, as well as increases in employment opportunities. The Energy Department will also carry out energy audits door to door that will confirm any improvement after energy-related expenditures, such as adding thermal insulation layers, decreasing air circulation, maintaining heating and cooling systems, and providing services that diagnose health and safety issues.

8.4.3 European Union

The EU has been an advocate for coping with climate change and providing initiatives to take appropriate actions to reduce emissions. Since the UK came up with the idea of a "low-carbon economy," in which the most important part is the enhancement of energy utilization efficiency, the EU member states have been given positive assessments at different levels and have adopted similar strategies. Under the leadership of France and Germany, the governments have invested enormously in the long run by promoting technological updates of the environment, energy, and relevant industries. At the same time, the EU has taken full advantage of the renewable energy and high energy-efficiency technologies to actively promote international cooperation about climate change and create the conditions for its enterprises to enter the environmental protection markets in the developing countries by technology transfers, of which many represent energy utilization technologies with high efficiencies. By a series of new measures, the EU goes even further to set completely open and flexible policies that are organized, attractive, and competitive—a "scientific research paradise." The EU mainly issues a series of directives to enhance its energy-efficiency standards of internal energy-consuming products and to initiate programs that promote the scientific study of energy in the EU, such as research and development network programs, joint technology development programs, coal and steel research, intelligent energy programs, and the 7th Framework Programme, which funds research and technological development. The energy plan aims to lead the EU economy in a high energy-efficiency and low-emission direction, becoming a world leader that is entering into the "Latter Industrial Revolution" era (Tonn and Peretz 2007).

8.5 Implications

Developed countries pay much attention to guiding and supporting various energy conservation activities, as well as giving full play to the basic role of market forces in allocating resources. In consideration of their specific national conditions and existing problems, these countries have adapted a series of fiscal and tax policies, as well as flexible measures in practice and achieved positive results. We obtained the following insights into improving our energy-saving system according to the lessons we learned from the developed countries, as well as from our current situation and development stage.

(1) Improve the management of the energy-efficiency mechanism with clear responsibilities at all levels.
According to the experience of developed countries, we should, at first, have clear responsibilities of the government, industry sector, and businesses at all levels, and we must, at the same time, establish a clear system of the divisions of energy efficiency management to improve the energy efficiency level. In January 1980, energy efficiency management was included in the governmental functions for the first time after the state council approved the *Report on Strengthening Energy Conservation* (NDRC [1980] No. 50). As China shifts to a market-oriented economic system, our government establishes and implements a series of strong energy efficiency policies, such as positive energy-saving investment policies, special funds for energy-saving infrastructure and technically upgrading projects, preferential interest rates for energy-saving project financing, and special prizes for energy savings, where monetary prizes are used to reduce the production costs and exclude bonus taxes. These policies have played a significant role at that time, but because of the transformation to a market-oriented economic system, the previous government agencies that were in charge of energy conservation could not work

well under the new economic conditions, so a top-down energy efficiency management system is the need of the hour. While comprehensive statistics of the energy usage in all units should be made available, specific responsibilities should be assigned to make a great contribution toward energy conservation. In addition to the government, professional energy-saving institutions that are responsible for advancing energy efficiency and organizing, managing, and extending energy-saving research and development projects are also needed. Today, we have energy-saving supervision centers and investment corporations, but we do not have large-scale and professional energy-saving institutions with comprehensive strategies. Such institutions should be set up to fully promote the energy efficiency levels.

At the corporate level, we have clear responsibilities of the key energy-using units and energy-saving producers to some degree. In 2006, the National Development and Reform Commission issued a notice entitled *1000 Enterprises Energy-saving Program*, which focuses on promoting energy conservation in the high energy-consuming industries. These industries consume 670 million tce, making up 33 % of the nation's total energy consumption and 47 % of the industrial energy consumption. This campaign is currently in good shape. Thousands of companies have achieved a total of 106.2 million tce in energy savings, which represents 106.2 % of the energy efficiency label system and is two years ahead of schedule. But these energy-intensive enterprises in China are somewhat passive in saving energy, as initiatives for and awareness of energy conservation are yet to materialize. There are several preconditions for energy-efficient policies to work well in the developed countries. Examples include the governments' binding targets for energy conservation, greater markets in the energy sector, setting standards and labels, the tax system, and other such basic measures. Saving energy is not the sole purpose of these policies. The policies also attempt to optimize taxes, enhance competition, and promote social equity, so these goals have to be considered. Furthermore, these policies should align with various policies for industry, trade, finance, and investment, as well as for transfer payments. We should further establish and perfect a comprehensive energy efficiency policy system according to our national conditions. Examples include coordinating incentives with regulations, perfecting the related supporting policies and measures, and strengthening the capabilities of the basic energy-saving measures such as the statistical database. Establishing and improving energy efficiency management mechanisms at all levels in our state system, setting clear responsibilities for each department, and building-up harmonious and well-ordered mechanisms can become powerful safeguards of the energy efficiency programs.

(2) Improve the energy efficiency standards and identification system and establish a national energy efficiency benchmark

The energy efficiency label system acts not only as a measure of whether energy has been saved or not but also as a strong measure that can be used to manage and control energy conservation. In addition, it acts as a criterion that establishes whether the energy-using units have really saved energy or not. Once the system is effectively implemented, it will be useful in curbing the energy consumption growth of appliances and industrial equipment and reducing the investment in energy supply infrastructure. By 2007, China had already issued 15 energy-efficient standards in total, involving 14 products and including the general principles for formulating the standard values and testing methods of energy consumption (efficiency) for household and similar electrical appliances. For example, the regulated values of efficiency and methods of measurement for radios, recorders, and electric fans, as well as the regulated values of energy consumption. Current energy-efficient standards include the basic product classification, regulated value of energy consumption (efficiency), energy conservation value assessment, testing method, and inspection rules. The limited value of energy efficiency should be enforced, mainly to eliminate high energy consumption products while an energy conservation value assessment is a voluntary index mainly used to provide the technical basis for our country's energy-efficient and product endorsement labeling system. So our current energy-efficiency standards are mandatory and they are based on specific items.

There are many flaws in our current energy efficiency standards, as their values for energy consumption (efficiency) and energy conservation value assessment are on the low side while the energy consumption quotas are drifting further away from the optimization points, which is bad for the energy-efficient utilization rates. The major reasons are as follows. First, the calculations show mismatches because of the inaccurate energy statistics. As a result, our energy efficiency standards do not coincide with the true energy situation, which harms the formulation and implementation of an optimal energy control system. Second, the current method for calculating the energy efficiency is unscientific, subjective, and random and does not adequately consider the differences among international trade, local energy situations, environmental qualities, and economic performance. The energy efficiency standards include only a few categories, such as some household appliances, electrical lighting, and industrial equipment. A comprehensive standard system has not materialized, so we should develop an energy-efficient standard system for business equipment, office equipment, and other industrial equipment. An energy-efficient standard system is a scientifically based complete system consisting of many intrinsically linked standards. It is used to show the many qualities of an energy-efficient standard system and it reflects the relationships among all of the standards throughout the energy sector.

Hence, we should accelerate the speed at which we compile our energy efficiency standards and refer to the energy efficiency levels in the developed countries. In addition, we need to plan for and extend the scope of our energy-efficient standard system and strengthen the implementation and evaluation of its effects based on the existing standards that have already been implemented in terms of household refrigerators, air conditioners, washing machines, electric motors, and energy-saving lamps. Moreover, we need to strengthen the supervision of our law-enforcement practices, organize specific inspections that reveal and prosecute false claims, and regulate the use of energy conservation logos. Furthermore, we need to implement energy-saving product certifications, extend our service scope, strengthen the energy certification process for industrial energy-consuming products, and enhance the credibility of our certifications.

(3) Expedite the marketing process of energy prices and promote energy-conservation via market-based means

Price is the strongest market signal in a market economy. True energy prices can give the right guidance for social investment in energy efficiency. In view of this fact, the governments in the market economy countries have often used energy prices as a most important energy conservation policy construct for many years. China's energy prices have been controlled by government regulations for decades. As China transfers to a market economy, its energy price mechanism is getting closer to the market regulations of developed countries. Coal and crude oil have realized perfect market-based pricing. Our crude oil price is linked with the international marketplace, but we hardly have any pricing power in the upstream production of crude oil. The reform of our oil pricing mechanism was completed in 2008, which linked our refined oil prices to global oil prices. The country's refined oil prices and products, tax reforms, fuel taxes, and transport prices were announced by the government. However, China's natural gas prices are lower than the various international prices, as the gas price still has a long way to go because of the high monopolization in the natural gas-producing areas and the infancy of market-oriented reform.

Energy price reform is a significant process that serves two general goals. On the one hand, from the viewpoint of our national strategy, we are passive and less influential towards the international energy pricing mechanism. However, in the long run, our energy prices will inevitably become market-based and line-up with international practices. In addition, the pricing mechanism should be used to reflect the energy cost by capping the high margins brought about by over-exploitation and directing the profit flows. On the other hand, in terms of the people's livelihood, greater marketization of energy may harm public interests under some circumstances. Even in the US, the 2005 Energy Policy Act, which relaxed the price controls, has made it harder to deter rising energy prices, harming the interests of the general public in the short run. Compared with other countries, China's per capita income and consumption levels are far behind. Hence, while our energy prices are lower, the extent of our public outlay costs may be relatively high. As the energy market is highly monopolistic, energy companies can easily pass on the cost to consumers. For example, the customs duties and tariffs may be used to pay for the cost of oil and gas price reforms. Therefore, there may be contradictions between the two objectives in terms of the trends of energy market pricing. It is highly important to control the reforms and make proper choices between long-term and short-term profits (Wang and Chen 2008).

(4) Research and development, demonstration and extension of energy-efficient technology

Fiscal policy supports energy-saving technological innovations and applications. Specific objectives include the following:

(1) Support the research and development of energy efficient technologies, especially the internationally advanced ones, and promote the leapfrogging of technological development
(2) Provide tax policy support when introducing advanced energy-efficient technology
(3) Support engineering research and the demonstration of important new energy-efficient technology
(4) Provide tax policy support toward producing, selling, and procuring energy-efficient products
(5) Support the development and distribution of market-based authoritative and reliable energy-efficient information. Indirect guidance promotes the application and dissemination of commercial energy-efficient technology

Overall, the current energy technologies and equipment levels of our mainstream production, including most of our industrial technologies and our standard of living, are relatively low, and there is a gap of 10–20 years between our energy efficiency levels and the internationally advanced levels. There are still many deficiencies in our current energy-saving technology-promotion policies and China has not built market-oriented enterprises as its mainstay or endorsed policies that support an energy-saving technically innovative system. Our investment in energy-saving scientific research is not enough, as the government's S&T appropriation in 2005 was 127 billion RMB (budgeted), which is less than 1 % of the country's GDP, and the energy-saving share was even smaller. Fiscal and taxation policies that promote energy-saving technological progress need to be further enhanced.

Technological progress is one of the basic ways to save energy. In the short run, we should transform our economic development mode by reducing our dependence on energy and achieving significant energy conservation; that is, fundamentally increasing our dependence on technical progress. Hence, fiscal policy should give enough support for researching and promoting new energy-saving technologies. The government should play an important role in harmonizing the development, promotion, and application of our energy-saving technologies and put more effort in supporting its fiscal policy to realize the recent "11th Five-Year Plan" energy reduction targets. These goals include expediting the development of the national innovation system and establishing and promoting a more perfect and systemic energy-saving technology research and policy system. These are the two major targets aimed at creating an energy-saving society in the long term.

(5) Nurturing citizens' awareness of energy conservation and paying attention to energy poverty
The improvement of the national energy picture relies not only on the production side and improvement of the energy efficiency of the equipment but also on all consumers so as to develop good energy habits and save energy on the consumption side. Energy savings is a major undertaking that relates to national development and progress in which everyone needs to work together. In addition, saving energy involves small tasks, where everyone can participate with little effort and can be actively involved from the start.
Since consumers are at a disadvantage in terms of the information asymmetry in the choice of energy-saving products, governments must advertize and popularize the effects of the different energy efficiency standards on saving electricity, and at the same time, accelerate the identification and formulation of energy efficiency standards so that people can choose the most energy-efficient products when buying household appliances, automobiles, and other energy-consuming products. As a backdrop to China's rapid urbanization and motorization processes, incrementally improving the energy-efficiency levels and guiding the healthy consumption patterns have great significance in improving the energy-efficiency levels and controlling the overall energy consumption.
Seriously promoting national energy policies and energy-saving measures at all levels of government, advertizing energy-saving tips and information, actively promoting energy conservation and new technologies and products, and organizing daily public campaigns can help people develop a conscious awareness of energy conservation and good energy-saving habits. Promoting energy-saving practices for all aspects of society, affirming and promoting energy-efficient models, and creating a positive atmosphere where people are "proud of saving energy and ashamed of wasting energy" raises public awareness of energy conservation and helps guide and establish a joint force focused on health and reduce the energy consumption of society.
With the rising international energy prices, where energy prices in China are in line with international standards, energy consumption has become an unbearable burden for low-income families. This is particularly true in the context of global warming, wherein the developed countries are putting pressure on China to reduce its greenhouse gas emissions. As a result, the impact of energy on poverty is both a current and future problem that the government should be particularly concerned about. One way to solve the problem is that the government subsidizes the poverty-stricken areas and families, which helps mitigate the costs of consuming energy. Another way is to construct the infrastructure of distributed energy, new and renewable energy, and small hydropower, which could sweep away the barriers to the poor in terms of gaining access to energy-associated equipments.

References

Foreign Affairs Department of National Development and Reform Commission (2005) The European Union energy conservation strategy and enlightenment. Chin Econ Trade Herald (23):32 and 33

IEA (2010a) Energy prices and taxes. International Energy Agency (IEA), Paris

IEA (2010b) Energy technology perspectives 2010. International Energy Agency (IEA), Paris

International Department of National Development and Reform Commission Training Center (2009) NDRC's abroad (boundary) training summary in 09 series 2–Training summary report of "Informationization of Enterprise Energy Saving Management". International Department of National Development and Reform Commission Training Center, Beijing

Kasahara S, Paltsev S, Reilly J et al (2007) Climate change taxes and energy efficiency in Japan. Environ Resour Econ 37(2):377–410

Li GD (2008) The energy saving measures in USA. Power Demand Side Manage 10(6):73–75

Ma SZ, Long WD, Ma HQ (2006) Energy performance of buildings directive and its implementation in EU countries. Heat Ventilating Air Conditioning 36(8):86–91

Price L, Galitsky C, Sinton J et al (2005) Tax and fiscal policies for promotion of industrial energy efficiency: a survey of international experience. Lawrence Berkeley National Laboratory, Berkeley

Shang L (2006) Japan's energy policy: evolution and structure. Econ Surv 5:51–58

Shi HX (2009) Energy conservation and emissions reduction strategy in EU. Energy Conserv Environ Prot 6:8–9

Tassey G (1998) Comparisons of U.S. and Japanese R&D policies. Strategic Planning and Economic Analysis Group, National Institute of Standards and Technology

Tonn B, Peretz JH (2007) State-level benefits of energy efficiency. Energy Policy 35 (7):3665–3674

Yang J, Yang SC (2008) Latest progress of Japan's energy saving, consumption reduction and the implications. Contemp Econ Jpn 2:158

Wang R, Chu CJ (2007) Japan's energy conservation experience and enlightenment. Energy Chin 29(5):35–40

Wang Z, Chen SH (2008) Energy price marketization need competition mechanism. Chin Dev Obs 1:11–13

Zhai Q, Kang YB, Niu B (2003) The characteristics of energy saving management in the United States and its enlightenment to China. Energy Chin 25(7):7–14

Chapter 9
Energy Saving Potential from End-Use Efficiency Improvements and Its Socioeconomic Impacts

With its rapid economic growth, China is now confronted with soaring pressures from both its energy supply and the environment. To deal with this conflict, "putting *energy conservation first*" is identified by the government as one of the fundamental principles of China's energy conservation program. However, since the investment in efficiency improvements reduces the cost of energy services, energy efficiency improvements will have rebound effects without additional energy and environment policies, which will offset at least some aspects of the initial energy savings. This chapter explores the impact of end-use efficiency improvements on China's economic growth, energy consumption, and CO_2 emissions and mainly focuses on discussions about the rebound effects and the impact of different energy and environmental policies on relieving the rebound effects. The research centers on the following questions:

- What impact will energy end-use efficiency improvements bring to China's social and economic development?
- Will China's current industrial and energy structures increase the energy efficiency improvements that are accompanied by the obvious rebound effects of CO_2 emissions?
- Which sectors will experience the obvious rebound effects?
- What are the results of alternative energy and environmental policies on reducing the rebound effects?

9.1 Energy Efficiency and Rebound Effects

In this chapter, China's Energy and Environmental Analysis (CEEPA) model will be used to study the impact of energy efficiency improvements on China's macro economy, energy consumption, and CO_2 emissions.

Y.-M. Wei and H. Liao, *Energy Economics: Energy Efficiency in China*,
DOI 10.1007/978-3-319-44631-8_9

China's economy is currently growing fast. With the growth in population, the promotion of urbanization, and the acceleration of industrialization, especially the rapid development of heavy industry and transportation, China's energy consumption will increase significantly. As a consequence, the conflict between energy supply and demand, as well as the related environmental problems, will become more apparent. To deal with the challenges of energy and the environment and to promote the development of a resource-saving and environment-friendly society, the Chinese government is paying unprecedented attention to energy-saving issues. A series of new policies and regulations have been issued, including the *Energy Conservation Law of the People's Republic of China* and *Medium- and Long-Term Energy Conservation Plan*. Among these, the *Medium- and Long-Term Energy Conservation Plan* (NDRC 2004) clearly proposes that China's guiding principles of energy conservation should emphasize the improvement of end-use energy efficiency, gradually transform the production and consumption patterns, develop a mechanism to ensure conscientiousness regarding energy-efficiency in companies and in society, expedite the development of an energy-saving society, and promote sustainable development by using energy efficiently. "The priority of energy conservation and efficiency-based work" is identified as one of the fundamental principles of China's energy conservation program (State Council of the People's Republic of China 2005).

According to the definition from the World Energy Council, "energy efficiency" refers to a reduction in the energy used for a given service (ONELG 2006). In 1973, the oil embargo proclaimed by OPEC made energy efficiency research a hot topic. Since then, extensive research has been conducted on how to facilitate the implementation of energy efficiency measures, as well as the potential of energy savings and/or emissions mitigation by improving energy efficiency, and how to assess the cost of investing in energy efficiency improvements (Boardman 2004; Clinch et al. 2001; Gellings et al. 2006; Jakob 2006; Laitner and Hanson 2006; Lang 2004; Lu 2006; Mahlia et al. 2002, 2004; Worrell et al. 2000).

Early research about energy efficiency mainly focused on its opportunities for improvement and its benefits (Hayes 1976; Lovins 1979). However, in the early 1980s, Khazzoom (1980) questioned the nature of the "rebound effect"[17]; that is, the investment in energy efficiency improvements lowers the cost of energy services and will offset (at least) some of the initial energy savings. Brookes (1990) further pointed out that if the decline in energy consumption per unit of output is cost-effective, it will lead to increased (rather than decreased) energy consumption in the entire economic environment. The ideas of Khazzoom and Brookes about the rebound effects of energy efficiency improvement are recognized by their successors. Many scholars have more recently discussed and analyzed the rebound effects. *Energy Policy* has even published a special edition in 2000 that discussed energy efficiency and rebound effects. Overall, the existence of rebound effects is generally accepted by researchers. The main contention is the scale of the rebound. Some researchers point out that the rebound effects only have a small scale. Laitner and Hanson's (2006) research, for instance, indicated that the rebound effects should only be 2–3 %, so energy efficiency policy itself could be very effective. Berkhout et al. (2000) and others hold the view that the effect could be up to 15 %. Based on reviews of more than 75 related studies, Greening et al. (2000) and others concluded that the rebound effect could be much lower than one. Other researchers, on the other hand, concluded that the effect may be large enough to lead to an increase in energy demand and emissions. For example, Brännlund et al. (2007) examined the influence of energy efficiency improvements on Swedish residential consumer choices and then on the corresponding emissions of CO_2, SO_2, and NO. They also examined the neutralization of a carbon tax on the rebound effects at the same time. Research shows that when energy efficiency rises, the emissions of CO_2, SO_2, and NO will all increase. The carbon tax must rise if CO_2 emissions need to return to their initial level before energy efficiency improves and the corresponding SO_2 emissions will decrease to a lower level than their initial level while an increase in NO cannot be eliminated completely. Herring (2006) also concluded that an improvement in energy efficiency would decrease the relative energy price and lead to a larger usage amount. He pointed out that because of the existence of rebound effects, more effective CO_2 policies should change their focus to the transfer of non-fossil energy resources, utilizing a carbon tax to subsidize non-fossil energy resources such as renewable energy resources. In the end, it is energy efficiency instead of energy conservation that is needed to limit energy consumption.

Discussion and measurement of the rebound effects are of great importance to promote the effective realization of energy savings and emission reductions by energy efficiency improvements. The research by Greene et al. (1999) and others pointed out that since the combined impact of technological advancement and rebound effects determines whether or not energy efficiency improvements will significantly reduce greenhouse gas (GHG) emissions, measuring the rebound effects is essential to the formation of effective GHG emission policies that reduce emissions. Although Greening et al. (2000) concluded that the scale of the rebound effects is very small, they still indicated that as the upper-bound estimates of the rebound effects suggest that energy efficiency improvements will increase rather than decrease energy demand, identifying the origin and scale of the rebound effects are very important in an effective design of CO_2 emission-reduction policies.

So far, there are very few studies that discuss and measure the potential rebound effects of improving China's energy efficiency. One exception is the research of Glomsrød and Wei (2005). Using a CGE model to study the influence of clean coal technology on China's environment, they found that due to the improvement of energy efficiency, and other reasons, there was a decline in transportation costs and that clean coal technology could boost the economy and decrease the emissions of particulate matter. However, since China has a relative surplus of labor supply, the corresponding rebound effect would be comparatively larger. The energy efficiency improvement brought about by clean coal technology would contribute toward an increase in China's total energy consumption, coal consumption, and CO_2 emissions. It is therefore necessary to intensify our discussion about the potential rebound effects in the process of improving domestic energy efficiency to effectively implement China's energy savings program.

The rebound effects include the direct, indirect, and general equilibrium effects. Among these, the general equilibrium effect includes the reaction of producers and consumers and reflects the large amount of adjustments in all the sectors' relationships between supply and demand (Herring 2006). To conduct a comprehensive analysis of the impact of energy efficiency improvements on China's energy sector and environment, this research analyzes the general equilibrium effect of energy efficiency improvements and compares various policies and procedures that have been implemented to relieve the rebound effects.

9.2 Analytical Tool: China's Energy and Environmental Policy Analysis Model

The CEEPA model was developed by the Center for Energy and Environmental Policy Research (CEEP). It is based on a computable general equilibrium (CGE) model.

9.2.1 Computable General Equilibrium Model

The CGE model stems from Walras' general equilibrium theory (Walras 1969). It describes the interactions among different behavioral subjects in a macroeconomic system using a set of simultaneous equations. Its basic notion is that producers make optimal investment decisions under resource restrictions and determine optimal amounts of supply according to the principles of profit maximization and cost minimization, whereas consumers make optimal expenditure decisions under budget restrictions and determine optimal amounts of demand according to the principle of utility maximization. The equilibrium price makes the optimal supply amount equal to the optimal demand amount, so there is the most rational usage of resources in which consumers get the greatest amount of satisfaction and the economy reaches a stable equilibrium status.

Although the general equilibrium theory model was proposed by Walras as early as 1874, it was not until the 1950s that the existence, uniqueness, and stability of a solution to the general equilibrium model was proven by Arrow and Debreu (1954). In 1967, Scarf (1967) developed a global convergence algorithm to calculate a fixed point, making the equilibrium price calculation technically possible. Since then, the CGE model has become a popular economic topic and a common policy-analysis tool extensively applied in various research and analyses of taxation, trade, income distribution, energy, the environment, agriculture, and so on.

The CGE model for energy studies was first applied in the 1970s (Hudson and Jorgenson 1974). In the early 1980s, the related research was further extended to include environment-related issues (Bhattacharyya 1996). So far, there has been extensive research based on the CGE model that includes both energy and environmental issues, including analyses and impact studies of energy/environment taxation (Bjertnæs and Fæhn 2008; Scrimgeour et al. 2005), energy prices (Doroodian and Boyd 2003; Klepper and Peterson 2006), energy efficiency improvement (Hanley et al. 2009; Sue Wing and Eckaus 2007), energy-related research and development investment (Fisher-Vanden and Sue Wing 2008; Müller-Fürstenberger and Stephan 2007), and so on.

The CGE model can describe the interactive functions of various markets and agents, and it can assess the direct, indirect, and economy-wide impacts of policy changes; thus, this model is very appropriate and should be applied in our study. Among the existing CGE-based studies about energy efficiency improvements, Grepperud and Rasmussen (2004) discussed the potential rebound effects of energy efficiency improvements using a CGE model describing Norway's economy. They respectively considered the impact of electricity efficiency improvements in such industries as paper and printing, metal manufacturing, chemical mining, and finance and insurance, as well as the impact of oil efficiency improvements in aquaculture and road transportation. Their research showed that the various sectors differed a lot in terms of the changes in energy consumption and GHG emissions. Among them, the manufacturing industry had the most significant rebound effect. Hanley et al. (2006) used a regional CGE model to analyze the influence of energy efficiency improvements on the economy and environment in Scotland. Their study showed that the same energy efficiency improvement in all sectors would indeed stimulate energy production and demand and worsen various environmental indices.

9.2.2 China's CEEPA Model

The prototype of the CEEPA model referenced the SO_2 emissions-tax model of Wu and Xuan (2002). The model included 16 industrial production sectors (agriculture, iron and steel, building materials, chemicals, non-ferrous metals, other heavy manufacturing, paper industry, other light manufacturing, construction, transportation and post and telecommunications, services, coal mining and refining, crude oil extraction, natural gas extraction, oil processing, and electric power), two classes of residents (urban and rural), and the government's economic behavior. The model also consists of five basic modules, including production, income, expenditures, investment, and foreign trade. For detailed introduction of the basic CEEPA model, please refer to the research of Q-M Liang (Liang et al. 2007, 2009). The following descriptions only represent the extensions and modifications of the basic CEEPA model for the energy efficiency improvement simulations.

9.2.2.1 Recognition of Energy Efficiency Improvements in the Model

According to the definition of energy efficiency and in reference to related research (Glomsrød and Wei 2005; Grepperud and Rasmussen 2004), an index describing the sectors' energy efficiency, $techE_i$, was introduced into the corresponding equations of the CEEPA model's production functions, as shown in Eqs. 9.1 and 9.2.

$$Energy_i = \left(\frac{1}{techE_i \cdot A_{KE,i}}\right)^{1-\sigma_{KE,i}} \cdot (1-\alpha_{K,i})^{\sigma_{KE,i}} \cdot \left(\frac{Pke_i}{Penergy_i}\right)^{\sigma_{KE,i}} \cdot KE_i \tag{9.1}$$

where,

$Energy_i$	composite energy input of sector i
KE_i	composite capital-energy inputs of sector i
Pke_i	cost of composite capital-energy inputs of sector i
$Penergy_i$	cost of composite energy input of sector i
R_i	user cost of capital of sector i
$A_{KE,i}$	shift parameter in the CES function (capital-energy) of sector i
$\alpha_{K,i}$	CES share parameter of capital in the capital-energy composition of sector i
$\sigma_{KE,i}$	substitution elasticity between capital and energy of sector i

$$Pke_i = \frac{1}{A_{KE,i}} \cdot \left(\alpha_{K,i}^{\sigma_{KE,i}} \cdot R_i^{1-\sigma_{KE,i}} + (1-\alpha_{K,i})^{\sigma_{KE,i}} \cdot \left(\frac{Penergy_i}{techE_i}\right)^{1-\sigma_{KE,i}}\right)^{\frac{1}{1-\sigma_{KE,i}}} \tag{9.2}$$

Note: $techE_i$ energy efficiency index in sector i (assigned a baseline value of unity for all sectors).

Note that we only examine the efficiency improvement of the production sectors and focus solely on end-use consumption in this study. In this study, no consideration is made of energy exploitation and transformation efficiencies. Therefore, our assumption is that there will be no improvement in energy efficiency for households and for the five energy-producing sectors (coal mining, crude oil products, natural gas products, petroleum refining, and electricity production and supply).

9.2.2.2 Decomposition of Electricity Production

To examine the effects of non-fossil fuel electricity production in moderating the rebound of CO_2 emissions, this study decomposes the electricity sector production according to the kinds of power generation (Fig. 9.1). Following the studies of Wing (2006, 2008) and Skeer and Wang (2006), the generation of the electric power sector was further divided into three basic activities using a nonlinear program model with bottom-up data (including installed capacity, overnight costs, operating costs, heat rate, capacity, and other factors for various kinds of power generation technologies): operations management, electric power transmission and distribution, and electricity generation. The current electricity supply in China is mainly composed of thermal, hydro, and nuclear power. Therefore, the model recognizes five technologies: coal-fired, petroleum-fired, natural gas-fired, hydroelectric power, and nuclear power.

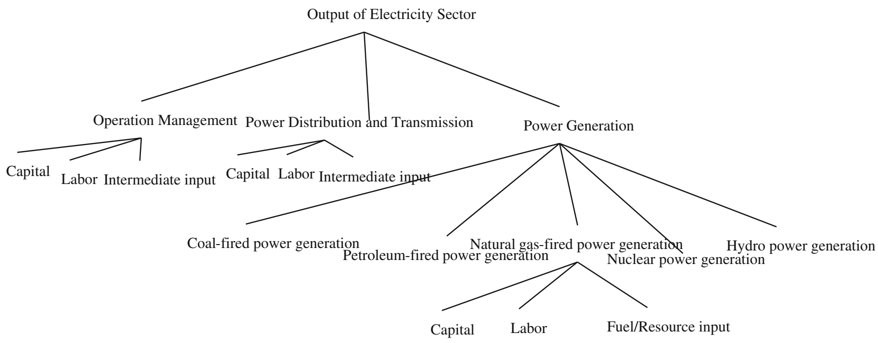

Fig. 9.1 Production structure of the electricity sector

9.2.2.3 Treatment of Capital Markets

For the capital markets, we also used the method of Wing (2008). That is to say, to represent the characteristics of an electrical power project, which has a long construction period and low capital liquidity, the capital supply in our model is divided into mobile capital and capital for specific technologies. To avoid the problem that completely fixed endowments of technology-specific capital may lead to a zero capital price when the corresponding type of generation operates below capacity, the technology-specific capital in our model is assumed to be partially reversible and we use a Constant Elasticity Transformation (CET) function to describe the adjustments among the mobile capital and various types of technology-specific capital. When clearing the capital markets, mobile capital and various types of technology-specific capital realize their respective supply–demand balances.

In addition, it is difficult to describe how producers adjust their investments among different types of electricity generation and technologies and in different periods within the recent decomposition models due to the lack of related data. Therefore, with reference to Wing's (2008) processing method, this study uses the static form of a decomposed CEEPA model.

9.2.2.4 Data Source and Parameter Calibration

The database for our CEEPA model is derived from a social accounting matrix (SAM). The parameters in the model include exogenous and endogenous parameters.

SAM is a matrix that expresses the national economy. It represents a detailed description of an economy in a country or region in a given period (usually one year). By integrating an input–output table and the national income accounts under a uniform framework, the matrix can describe the interdependence among sectors and the income and expenditure status of all agents, providing a comprehensive overview of total economic activity. In this study, we calculated the China SAM based on a 2002 input–output table (NBS-DNA 2006), as well as miscellaneous yearbooks and associated literature.

Identification of the endogenous parameters was based on a certain method of calibration. Specifically, the data in the SAM were substituted into each equation as the base year equilibrium data. The equations were then solved to show the value of the parameters.

Exogenous parameters in this model include miscellaneous substitution elasticities, carbon emission factors of various fossil fuels, the fraction of oxidized carbon, the composition matrix of fixed capital, the total factor growth rate, the salary growth rate, and so on. The setting of these parameters mainly refers to related research (Wing 2008; Wang 2003; Wu and Xuan 2002; Xue 1998), together with our own adjustments.

In particular, the "bottom-up" data (including installed capacity, overnight costs, operating costs, heat rate, capacity, and other factors for various kinds of power generation technologies) that were used to decompose the electricity sector were collected from the *China Electric Power Yearbook* and related literature in association with our own adjustments (Skeer and Wang 2006; Wing 2006).

9.3 End-Use Efficiency Analysis Without Additional Energy and Environmental Policies

This section explores the impact of energy end-use efficiency improvements by sector on China's macro-economy, energy usage, and related CO_2 emissions without additional energy and environmental policies.

A baseline scenario was first run, in which there are no energy efficiency improvements and no additional energy/environmental policies. Scenarios with either energy efficiency improvements or the introduction of additional policies were subsequently run and then compared with the baseline scenario. The results in terms of the percentage deviations from the corresponding baseline values are shown in Tables 9.1 and 9.2.

Table 9.1 shows the changes in the major macroeconomic indices in response to a uniform energy end-use efficiency improvement of 5 % for all sectors.

The results show that the efficiency improvement will boost production in all sectors. As shown in Table 9.1, the output of all sectors increases and the largest increase corresponds to the construction industry. Other sectors where the increase is above average include building materials, iron and steel, non-ferrous metals, other heavy industries, chemicals, transportation, and agriculture, respectively. It can also be seen from Table 9.1 that by stimulating the production of all sectors (especially the two labor-intensive sectors of construction and agriculture), an improvement of energy end-use efficiency will increase the labor demand in all sectors. This will, in turn, drive-up the total labor income, given the assumption of a rigid wage rate as labor income dominates total household income (e.g., in the

Table 9.1 Impact of a 5 % improvement in end-use energy efficiency on macroeconomic indicators for all sectors (%)

(A) *Aggregate indices*			
GDP	1.543	Total consumption	1.372
Total investment	2.547	Urban household consumption	1.376
Capital (fixed)	2.592	Rural household consumption	1.362
Capital (working)	1.519	Urban household disposable income	1.703
Labor demand	1.612	Rural household disposable income	1.629
(B) *Sectoral indices*			
	Sectoral output	Sectoral labor demand	Sectoral profit
Agriculture	1.534	1.619	1.897
Iron and steel	2.094	1.653	1.374
Building materials	2.263	1.737	1.315
Chemical	1.761	1.297	1.039
Non-ferrous metals	2.050	1.544	1.218
Paper	1.301	1.465	1.691
Other heavy industries	1.903	2.066	2.280
Other light industries	1.268	1.547	1.878
Construction	2.514	2.520	2.597
Transportation	1.626	1.454	1.393
Service	1.053	1.405	1.838
Coal mining	0.505	0.926	1.446
Crude oil products	0.111	0.936	1.526
Natural gas products	0.147	0.724	1.189
Petroleum refining	0.394	0.938	1.380
Electricity production and supply	0.487	0.795	1.993
Sectoral average	1.313	1.414	1.628

baseline scenario, the shares of labor income of the total income for urban and rural households are 72.9 and 90.6 %, respectively). As shown in Table 9.1, both urban and rural household disposable incomes also increase and this response further magnifies total household consumption.

Given the assumption of a fixed marginal savings rate, an increase in household disposable income will correspondingly drive up household savings. Besides sectoral output, it can be seen from Table 9.1 that the profits in all sectors also increase. Given the assumptions of a fixed enterprise tax rate and a fixed enterprise transfer rate to households, an increase in sectoral profits implies a corresponding increase in enterprise savings. An increase in sectoral outputs and profits leads to an increase in government revenues from production taxes and enterprise taxes,

Table 9.2 Energy/environmental impact of a uniform energy end-use efficiency improvement of 5 % for all sectors (%)

(A) *Aggregate indices*			
Energy intensity	−1.038	Carbon intensity	−1.034
Total energy use	0.465	Carbon/TPES	0.027
Coal use	0.531	CO_2 emissions	0.492
Crude oil use	0.355		
Natural gas use	0.510		
Hydropower use	0.203		
Nuclear power use	0.082		
(B) *Sectoral indices*			
	Fossil fuel use	CO_2 emissions	
Agriculture	0.703	0.856	
Iron and steel	0.225	0.302	
Building materials	0.172	0.259	
Chemical	−0.141	−0.038	
Non-ferrous metals	0.023	0.163	
Paper	0.526	0.617	
Other heavy industries	1.116	1.197	
Other light industries	0.709	0.801	
Construction	1.368	1.569	
Transportation	0.188	0.343	
Service	0.647	0.783	
Coal mining	0.797	0.856	
Crude oil products	0.794	0.913	
Natural gas products	0.594	0.666	
Petroleum refining	0.681	0.410	
Electricity production and supply	0.309	0.307	

respectively. In addition, an increase in household tax revenues resulting from an increase in household incomes will further raise total government revenues and subsequently increase government savings. Enterprise savings, household savings, and government savings make up the major components of total savings. Thus, the augmentation of these three kinds of saving will ultimately drive up total savings. According to the closure principle of an investment–savings balance in our model, total investment transforms endogenously from total savings. As a consequence, as shown in Table 9.1, total investment, especially total fixed capital, increases. A rise in both total investment and total consumption boosts GDP. From prior discussions, it is apparent that an improvement in energy end-use efficiency has an obvious forward-driving effect on economic growth.

Table 9.2 shows the variations in the major energy/environmental indices induced by a uniform energy end-use efficiency improvement of 5 % for all sectors.

The results of Table 9.2 show that an efficiency improvement of the same magnitude for all sectors induces a reduction in both the energy use and carbon emission intensities. However, these reductions cannot guarantee any corresponding alleviation of the pressures on energy demand or the environment. As shown in Table 9.2, the demand for various energy inputs increases. This leads to an increase in total energy use. Among the various categories of energy, the increase for coal is the largest and it is closely followed by the increase for natural gas and, subsequently, crude oil, hydropower, and nuclear power. Since the amplitude of the increases for the three fossil fuels are all larger than those of the two primary power sources (as shown in Table 9.2), the carbon/TPES index increases, indicating a deteriorating emissions structure. Finally, the increase in both total energy use and the carbon/TPES index results in an increase in total CO_2 emissions. Therefore, it can be deduced that without additional restrictions, a uniform improvement of the energy end-use efficiencies of the same amplitude across sectors will increase rather than decrease the pressures on energy resources and the environment.

As for the impacts at the sectoral level, the total fossil fuel demand and CO_2 emissions increase in all sectors, except the chemical industry. In line with the variations in sectoral output, the largest increase for both fossil fuel demand and CO_2 emissions is in the construction industry.

Figure 9.2 illustrates the variations in economic growth and the major energy/environmental indices when there is a 5 % improvement in energy end-use efficiency for each individual sector, respectively.

Figure 9.2 shows that improvement of energy end-use efficiency in any of these sectors will promote economic growth and reduce energy intensity. Both the largest increase in GDP and decrease in energy intensity correspond to the chemical industry. A 5 % improvement in the energy end-use efficiency in this sector will drive up GDP by 0.31 % and reduce energy intensity by 0.25 % compared with the baseline level. Other sectors whose forward-driving effects surpass the GDP sectoral average include transportation, other heavy industries, services, and iron and steel. The sectors with backward-driving effects of energy intensity that fall below the sectoral average include iron and steel, building materials, transportation, and other heavy industries.

However, from the perspective of the impact on the magnitude of energy demand, the amount of CO_2 emissions and the emissions structure, each sector is different after an improvement in energy efficiency. Figure 9.2 indicates that except for the building materials, construction, and iron and steel industries, efficiency improvement in any of the other sectors will drive up total fossil fuel and energy demand and CO_2 emissions, where the largest increase in these three indices corresponds to efficiency improvements in the transportation industry, which is closely followed by the service industry. Other sectors where the efficiency improvements increase fossil fuel demand and CO_2 emissions that surpass the sectoral average include other heavy industries, chemicals, and other light industries.

Among the three sectors whose efficiency improvements will not raise energy demand and CO_2 emissions, the largest backward-driving forces for both indices occur in the building materials industry. Although efficiency improvements in

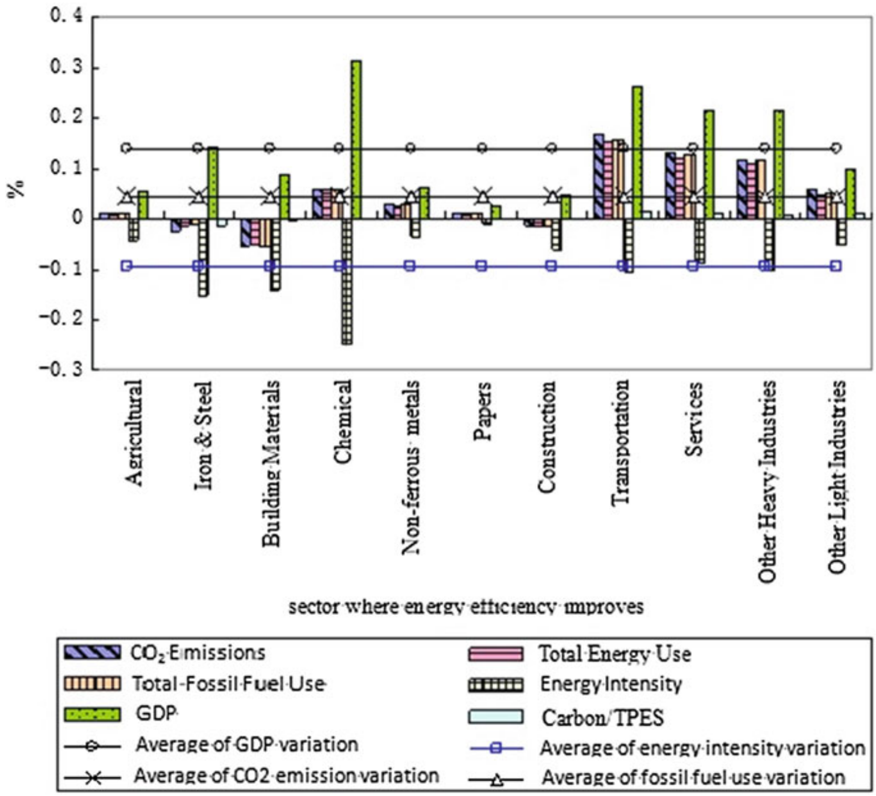

Fig. 9.2 Variations of GDP and the major energy/environmental indices when there is a 5 % improvement in energy end-use efficiency in each individual sector, respectively (%)

construction result in a greater decrease in fossil fuel usage and total energy demand than efficiency improvements in iron and steel, the latter sector is more conducive to improving its emissions structure and therefore shows a stronger response in reducing CO_2 emissions.

The prior analysis shows that energy end-use efficiency improvements in the iron and steel, building materials, and construction industries are generally favorable to reducing total fossil fuel demand and CO_2 emissions. This result allows for the possibility that one can neutralize the total rebound effect by accelerating the efficiency improvements in these three sectors. For example, Fig. 9.3 presents the changes in the major energy/environmental indices when the efficiencies in these three sectors improve by between 1 and 10 % (at 1 % intervals) while the efficiencies in the other sectors improve by 1 %.

The results show that compared with the uniform efficiency improvement by sector case (where energy end-use efficiencies in iron and steel, building materials, and construction also only improve by 1 %), coal demand, total energy demand,

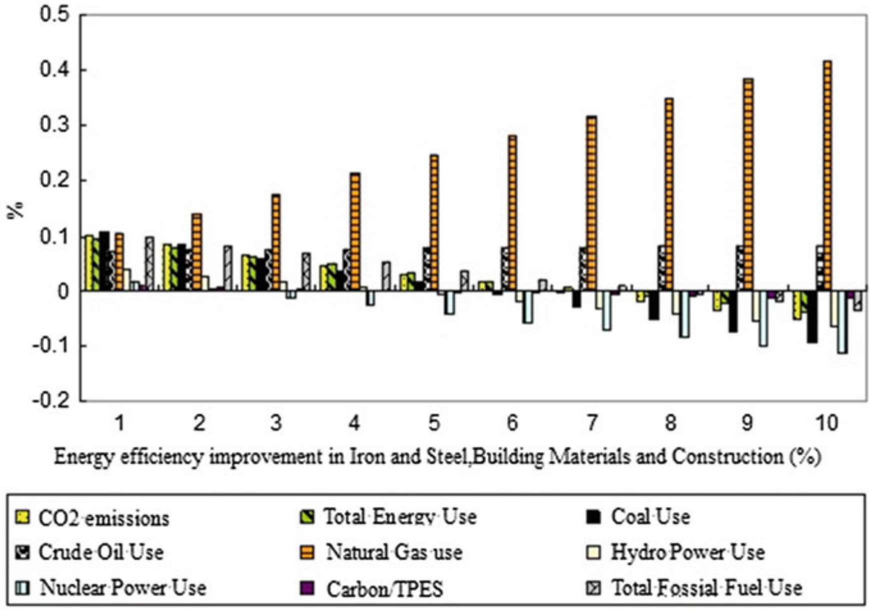

Fig. 9.3 Changes in the major energy/environmental indices under different differential efficiency improvements by sector (%)

and total CO_2 emissions under all differential efficiency improvement cases appear to have lower rebound effects. The larger the efficiency improvements in the iron and steel, building materials, and construction industries compared with those in the other sectors, the greater the moderating effects on the rebounds from these three indices. When efficiency improvements in the iron and steel, building materials, and construction industries all reach 7 %, coal demand decreases and the increases in fossil fuel demand and total energy demand are only 0.008 and 0.004 %, respectively, compared with the corresponding baseline values. Moreover, CO_2 emissions are completely eliminated (compared with the corresponding baseline value). Therefore, by accelerating efficiency improvements in these three sectors, the rebound effects of energy demand and CO_2 emissions could be effectively reduced. However, on the other hand, the potential of efficiency improvements in certain sectors within a given period is limited. Hence, under the feasible differential efficiency improvement scenario, the extent to which the rebounds of energy demand and CO_2 emissions could be reduced by sector would also be limited. On the other hand, Fig. 9.3 indicates that the differential efficiency improvements by sector barely affect the rebound of crude oil demand. In fact, oil demand in these instances is even larger than that under the uniform efficiency improvement case. Moreover, the differential efficiency improvement cases are not favorable to increases in primary energy demand and, accordingly, are not favorable toward a quick decrease in the carbon/TPES index. Therefore, it is necessary to explore how to introduce proper energy/environmental policies that complement the technical measures with economic measures and accelerate an improvement in the emissions structure.

9.4 Effects of Alternative Energy/Environmental Policies

9.4.1 Policy Scenarios

Rebound effects are mainly induced by the stimulation of energy demand through the decline in the relative prices of energy. As a consequence, the corresponding economic measures for reducing demand could be either the introduction of related tax policies (to counter the decline in the relative prices of energy) or the subsidization of primary energy resources that shifts the energy consumption toward non-fossil fuels and improves the development of an environment-friendly energy structure. As one aspect of the rebound effects of energy demand from energy efficiency improvements comes from the increase in non-fossil energy use, this aspect of a demand increase will not augment the environmental stress. Therefore, a carbon tax, which is one kind of taxation measure, will be introduced into the analysis; that is, our attention will be more focused on reducing the rebound of CO_2 and fossil energy demand, especially coal demand. In this analysis, we explore the subsidization of hydropower and nuclear power. Six scenarios are established, including a reference scenario (EI) and five policy scenarios, as shown in Table 9.3.

Scenario EI assumes a uniform improvement of energy end-use efficiencies of 5 % without the additional introduction of energy/environmental policies. Scenario EIC assumes a carbon tax on the basis of scenario EI with an endogenous tax rate that keeps the CO_2 emissions at their baseline level while all tax revenues are assigned to the government budget. Scenario EISH assumes a subsidy for hydropower generation with government income on the basis of scenario EI. Scenario EISN assumes a subsidy for nuclear power generation with government income on the basis of scenario EI. To compare the efficiency of different policies,

Table 9.3 Policy scenarios

Scenarios	Descriptions
Scenario EI	Efficiency improvement
Scenario EIC	Efficiency improvement + carbon tax
Scenario EISH	Efficiency improvement + subsidize hydropower
Scenario EISN	Efficiency improvement + subsidize nuclear
Scenario EICSH	Efficiency improvement + carbon tax + subsidize hydropower
Scenario EICSN	Efficiency improvement + carbon tax + subsidize nuclear

the magnitude of the economic disturbances introduced by all policies is set to be the same. Therefore, the values of the total subsidy in scenarios EISH and EISN are both set to equal the total carbon tax revenues in scenario EIC. Scenario EICSH assumes a carbon tax on the basis of scenario EI with all tax revenues assigned to the subsidy of hydropower. Scenario EICSN assumes a carbon tax on the basis of scenario EI with all tax revenues assigned to the subsidy of nuclear power. Similarly, to compare the efficiency of different policies, both the carbon tax rates (in scenarios EICSH and EICSN) are endogenous and generate the same amount of revenues as in scenario EIC.

9.4.2 Results and Analysis

Table 9.4 presents the changes in the major energy/environmental indices under different scenarios. From the perspective of the impact on energy demand, all five policies can reduce the rebound effects of coal demand. Compared with the baseline value, coal demand decreases under the three carbon tax scenarios. The greatest decrease corresponds to scenario EICSH while the smallest decrease corresponds to scenario EIC. As for the other two non-carbon tax policies, the one subsidizing hydropower shows a better result in moderating the rebound in coal demand than the one subsidizing nuclear power. All of the five policies can reduce the rebound for crude oil demand, although none can avoid an increase in crude oil demand from the baseline level. The largest moderating effect corresponds to the two hybrid policies, which combine taxing carbon emissions and subsidizing primary energy usage. The smallest moderating effect results from the two policies that solely subsidize primary energy demand. The rebound from using natural gas could be partially neutralized under the three carbon-tax scenarios but augmented under the two scenarios that solely subsidize primary energy demand. As for the impact on primary energy demand under the four scenarios where primary energy usage is subsidized, the demand for primary energy increases significantly, in which the

Table 9.4 Changes in the energy/environmental indices under different scenarios (%)

Index	EI	EIC	EISH	EISN	EICSH	EICSN
Total energy use	0.463	0.032	0.772	0.626	0.338	0.193
Coal use	0.531	−0.105	0.128	0.259	−0.510	−0.378
Crude oil use	0.355	0.226	0.301	0.301	0.170	0.171
Natural gas use	0.510	0.313	0.543	0.512	0.345	0.315
Primary power use	0.193	0.532	7.872	4.832	8.197	5.167
CO_2 emissions	0.500	0.000	0.184	0.283	−0.317	−0.218
Energy intensity	−1.041	−1.491	−1.362	−1.244	−1.813	−1.695
Carbon/TPES	0.037	−0.032	−0.583	−0.341	−0.653	−0.410

corresponding increases are obviously larger than those from the other types of energy demand. This could explain why the rebound of total energy use increases under scenarios EISH and EISN compared with scenario EI. However, as the increase in energy demand under these four scenarios mainly results from the increase in primary energy demand (the combustion of which will not produce CO_2 emissions) compared with that in the other scenarios, the emission structures under these four scenarios have clearly improved. Among them, the improvements of emission structures under the two scenarios that subsidize hydropower (EICSH and EISH) are larger than those under the two scenarios subsidizing nuclear power (EICSN and EISN). As for the changes in CO_2 emissions, all of the three policies that apply a carbon tax could completely avoid any increase in CO_2 emissions compared with the baseline level. The CO_2 emissions under scenarios EICSH and EICSN are less than the baseline level. Although both of the emission structures of scenarios EISH and EISN are clearly better than that of scenario EIC, coal demand under these two scenarios increases compared with the baseline level. The moderating rebound effects on crude oil demand and natural gas demand under these two scenarios are much weaker than those under scenario EIC. The combined result is that neither of these two scenarios can completely avoid an increase in CO_2 emissions compared with the baseline level. Summing up the above discussion and from the perspective of the moderating rebound effect on CO_2 emissions, when introducing the same magnitude of economic disturbances, the policy of solely subsidizing nuclear power turns out to be the weakest, followed by the policy of solely subsidizing hydropower. The effects of the two policies that solely subsidize primary energy use are both weaker than the policy that solely taxes carbon (EIC). The best result corresponds to the policy that combines taxing carbon emissions and subsidizing hydropower (EICSH).

The introduction of either a carbon tax or a subsidy implies a new distortion to the economic system. Therefore, it is necessary to examine the macroeconomic impact of these policies. Table 9.5 shows the changes in the major macroeconomic indices under different policy scenarios. The results show that the changes are similar, where the differences between the largest and smallest values for each index are merely 0.066 (GDP) and 0.108 (total consumption) percentage points. Hence, a comparison of different policies should focus on their energy/environmental effects.

Table 9.5 Changes in the macroeconomic indices under different scenarios (%)

Index	EIC	EISH	EISN	EICSH	EICSN
GDP	1.504	1.567	1.540	1.528	1.501
Total consumption	1.307	1.415	1.384	1.349	1.318
Total investment	2.517	2.563	2.526	2.532	2.496
Total export	1.415	1.474	1.451	1.428	1.404
Labor demand	1.546	1.639	1.606	1.572	1.539

9.5 Discussion of Policies on Energy Efficiency Improvement

According to the results from the CEEPA model, we reach the following conclusions and give the following policy advice:

(1) Energy end-use efficiency improvements should be accelerated in the iron and steel, building materials, and construction industries.
The model results show that when the efficiency improvement is uniform across sectors, the rebound will be apparent for both the fossil fuel demand and CO_2 emissions. For example, with a uniform efficiency improvement of 5 %, both the fossil fuel demand and CO_2 emissions will increase by approximately 0.5 % compared with the baseline scenario (no efficiency improvement).

The results of the individual sector efficiency improvements show that the energy end-use efficiency improvements will not lead to an increase in fossil fuel energy demand and CO_2 emissions. In this study, the three industrial sectors whose efficiency improvement will not drive up the total demand for fossil fuels and CO_2 emissions compared with the baseline level are iron and steel, building materials, and construction. The results of the differential improvements in energy efficiency by sector indicate that if the efficiencies of the above three sectors improve by 2–6 % when the efficiencies in the other sectors improve by 1 %, the total incremental CO_2 emissions from the baseline level will be reduced by 17.8–86.6 % compared with a uniform 1 % improvement across all sectors. If the efficiency improvement for all three sectors is 7 %, the total incremental CO_2 emissions are completely removed. In this case, we should accelerate the energy end-use efficiency improvements in these three sectors to take advantage of the ability of these three sectors to moderate the rebound of total fossil fuel demand and CO_2 emissions.

(2) Efforts to improve the energy end-use efficiency across sectors should be combined with efforts to set related energy/environmental policies. The relatively preferred way to neutralize the rebound effects is to combine carbon taxes with subsidizing hydropower.
Although the rebound in terms of fossil fuel demand and CO_2 emissions can be moderated by promoting higher efficiency improvements in the iron and steel, building materials, and construction industries, one should recognize that the potential efficiency improvements in these sectors are not limitless in a given period. Hence, there is a limited potential for neutralizing the total rebound effects. Therefore, the effort to improve energy end-use efficiencies should not be restricted to the implementation of a single policy.

The results of our policy analysis show that all of the five policies that either introduce a carbon tax or subsidize primary energy use can reduce the rebound of both fossil fuel demand and CO_2 emissions. Based on the same magnitude of economic disturbances, all the three carbon-tax policies show stronger moderating effects on the rebound of all kinds of fossil fuels than those of the two policies that solely subsidize primary energy use. All the four policies that subsidize primary energy use can significantly stimulate its demand and exhibit much better effects on improving the emissions structure than those policies that solely tax carbon emissions. Moreover, all the five policy scenarios are more in favor of reducing the energy intensity than the scenario where no additional energy/environmental policy exists (scenario EI). The backward-driving effects of energy intensity for the two policies that solely subsidize primary energy use turn out to be weaker than those policies that solely tax carbon while the two hybrid policies are better than the policy that solely taxes carbon. Among the five policies, the best policy combination is taxing carbon and subsidizing hydropower. This policy shows the strongest moderating effect on the rebound of coal and crude oil demand. As a consequence, its moderating effect on the rebound of total fossil fuel demand is also the strongest. At the same time, the decreases in the energy intensity and the carbon/TPES index induced by this policy are also the largest. The combined effect is that this policy has the best overall effect in moderating the rebound of CO_2 emissions. Therefore, one relatively preferred way to neutralize the rebound effects is to combine taxing carbon with subsidizing hydropower.

9.6 Summary

Energy end-use efficiency improvements that emphasize energy savings is one of China's future main objectives. Based on our energy and environmental policy analysis using the CEEPA model, this chapter assessed the general equilibrium effect of energy end-use efficiency improvements on China's economic growth, energy consumption, and CO_2 emissions. Seven scenarios were examined in our analysis: business as usual, end-use efficiency improvement without additional energy and environmental policies, and the five scenarios that introduced additional energy and environmental policies (carbon tax, subsidizing hydropower, subsidizing nuclear power, carbon tax plus subsidizing hydropower, and carbon tax plus subsidizing nuclear power). The results show that a uniform improvement in energy end-use efficiency across sectors will increase rather than decrease the total energy consumption and CO_2 emissions. A sensitivity analysis of sectoral efficiency improvements shows that the efficiency improvements in different sectors obviously have different rebound effects. Among the sectors, the efficiency improvements in the iron and steel, building materials, and construction industries will not drive up the total demand of fossil fuels and CO_2 emissions compared with their baseline levels. Therefore, energy end-use efficiency improvements should be sector-specific. The energy-saving potential of each sector and the potential to ease the total rebound effects should all be considered when differentiating the energy-saving goals of different sectors. Since the potential efficiency improvement for a certain sector would not be limitless over a given period, technical means should be implemented in association with related energy/environmental policies. The results show that the relatively preferred way to neutralize the rebound effects is to combine taxing carbon with subsidizing hydropower.

References

Arrow KJ, Debreu G (1954) Existence of an equilibrium for a competitive economy. Econometrica 22(3):265–290

Berkhout PHG, Muskens JC, Velthuijsen JW (2000) Defining the rebound effect. Energy Policy 28(6–7):425–432

Bhattacharyya SC (1996) Applied general equilibrium models for energy studies: a survey. Energy Econ 18(3):145–164

Bjertnæs GH, Fæhn T (2008) Energy taxation in a small, open economy: social efficiency gains versus industrial concerns. Energy Econ 30(4):2050–2071

Boardman B (2004) Achieving energy efficiency through product policy: The UK experience. Environ Sci Policy 7(3):165–176

Brännlund R, Ghalwash T, Nordström J (2007) Increased energy efficiency and the rebound effect: effects on consumption and emissions. Energy Econ 29(1):1–17

Brookes LG (1990) Energy efficiency and the greenhouse effect. Energy Environ 1(4):318–333

Clinch JP, Healy JD, King C (2001) Modelling improvements in domestic energy efficiency. Environ Model Softw 16(1):87–106

Department of National Accounts of National Bureau of Statistics (2006) China input-output table 2002. China Statistics Press, Beijing

Doroodian K, Boyd R (2003) The linkage between oil price shocks and economic growth with inflation in the presence of technological advances: a CGE model. Energy Policy 31(10): 989–1006

Fisher-Vanden K, Sue Wing I (2008) Accounting for quality: issues with modeling the impact of R&D on economic growth and carbon emissions in developing economies. Energy Econ 30(6):2771–2784

Gellings CW, Wikler G, Ghosh D (2006) Assessment of U.S. electric end-use energy efficiency potential. Electr J 19(9):55–69

Glomsrød S, Wei T (2005) Coal cleaning: a viable strategy for reduced carbon emissions and improved environment in China? Energy Policy 33(4):525–542

Greene DL, Kahn JR, Gibson RC (1999) Fuel economy rebound effect for U.S. household vehicles. Energy J 20(3):1

Greening LA, Greene DL, Difiglio C (2000) Energy efficiency and consumption–the rebound effect–a survey. Energy Policy 28(6–7):389–401

Grepperud S, Rasmussen I (2004) A general equilibrium assessment of rebound effects. Energy Econ 26(2):261–282

Hanley ND, McGregor PG, Swales JK et al (2006) The impact of a stimulus to energy efficiency on the economy and the environment: a regional computable general equilibrium analysis. Renew Energy 31(2):161–171

Hanley N, McGregor PG, Swales JK et al (2009) Do increases in energy efficiency improve environmental quality and sustainability? Ecol Econ 68(3):692–709

Hayes D (1976) Energy: the case for conservation. Worldwatch Institute, Washington DC, p 77

Herring H (2006) Energy efficiency–a critical view. Energy 31(1):10–20

Hudson EA, Jorgenson DW (1974) U.S. energy policy and economic growth, 1975–2000. Bell J Econ Manage Sci 5(2):461–514

Jakob M (2006) Marginal costs and co-benefits of energy efficiency investments: the case of the Swiss residential sector energy policy 34(2):172–187

Khazzoom JD (1980) Economic implications of mandated efficiency standards for household appliances. Energy J 1(4):21–39
Klepper G, Peterson S (2006) Marginal abatement cost curves in general equilibrium: the influence of world energy prices. Resour Energy Econ 28(1):1–23
Laitner JAS, Hanson DA (2006) Modeling detailed energy-efficiency technologies and technology policies within a CGE framework. Energy J (special issue):151–169
Lang S (2004) Progress in energy-efficiency standards for residential buildings in China. Energy Build 36(12):1191–1196
Liang Q-M, Fan Y, Wei Y-M (2007) Carbon taxation policy in China: how to protect energy- and trade-intensive sectors? J Policy Model 29(2):311–333
Liang Q-M, Fan Y, Wei Y-M (2009) The effect of energy end-use efficiency improvement on China's energy use and CO2 emissions: a CGE model-based analysis. Energ Effi 2(3):243–262
Lovins AB (1979) Soft energy paths: toward a durable peace. Harper & Row, New York
Lu W (2006) Potential energy savings and environmental impact by implementing energy efficiency standard for household refrigerators in China. Energy Policy 34(13):1583–1589
Mahlia TMI, Masjuki HH, Choudhury IA (2002) Theory of energy efficiency standards and labels. Energy Convers Manag 43(6):743–761
Mahlia TM, Masjuki HH, Saidur R et al (2004) Viewpoint: mitigation of emissions through energy efficiency standards for room air conditioners in Malaysia. Energy Policy 32(16):1783–1787
Müller-Fürstenberger G, Stephan G (2007) Integrated assessment of global climate change with learning-by-doing, energy-related research, development. Energy Policy 35(11):5298–5309
National Development and Reform Commission (2004) Long-term Energy Saving Special Planning (Fa Gai Huan Zi [2004] no. 2505)
Office of the National Energy Leading Group (2006) Energy efficiency and energy saving
Scarf H (1967) The approximation of fixed points of a continuous mapping. SIAM J Appl Math 15(5):1328–1343
Scrimgeour F, Oxley L, Fatai K (2005) Reducing carbon emissions? the relative effectiveness of different types of environmental tax: the case of New Zealand. Environ Model Softw 20(11):1439–1448
Skeer J, Wang Y (2006) Carbon charges and natural gas use in China. Energy Policy 34(15): 2251–2262
State Council of the People's Republic of China (2005) Decision on Establishing the National Energy Leading Group by the State Council (Guo Fa[2005] no. 14)
Sue Wing I, Eckaus RS (2007) The implications of the historical decline in US energy intensity for long-run CO_2 emission projections. Energy Policy 35(11):5267–5286
Walras L (1969) Elements of pure economics. Augustus M Kelley, New York
Wang C (2003) Simulation and uncertainty analysis of climate change policy: dynamic CGE model of China. Tsinghua University, Beijing
Wing IS (2006) The synthesis of bottom-up and top-down approaches to climate policy modeling: electric power technologies and the cost of limiting US CO_2 emissions. Energy Policy 34 (18):3847–3869
Wing IS (2008) The synthesis of bottom-up and top-down approaches to climate policy modeling: electric power technology detail in a social accounting framework. Energy Econ 30(2): 547–573
Worrell E, Martin N, Price L (2000) Potentials for energy efficiency improvement in the US cement industry. Energy 25(12):1189–1214
Wu YJ, Xuan XW (2002) Environmental tax economic theory and the application in China. Economic Science Press, Beijing
Xue XM (1998) Calculation of the carbon dioxide emissions of China energy and its international comparison. Found Environ Sci 4:27–28

Chapter 10
Prospects of China's Energy Efficiency

China is the biggest developing country in the world, whose energy problems have become significant strategic issues that restrict economic and social development. One important approach to solving these problems is to improve energy efficiency. China is in the process of industrialization, urbanization, marketization, internationalization, and information technology advancements, which can bring significant and important opportunities, as well as great challenges, in improving energy efficiency. Industrialization leads to an industrial structure that consumes a great amount of energy and promotes various technologies according to the types of energy sources. Urbanization affects the level that people consume energy, and it may boost the development of compact and intensive types of consumption that can increase the usage ratio of infrastructure. Marketization may increase the costs of basic energy consumption for middle-income and poor households, which can improve energy savings. Internationalization, on the one hand, may lead to the export of a great number of products that require high-energy inputs. On the other hand, it favors advanced technologies that save energy. Information technology can sharply decrease energy consumption through various direct or indirect actions. Research on the challenges we face when attempting to improve China's energy efficiency has been the focus of the last chapters. In this chapter, we will discuss the following questions:

- What specific opportunities are available when improving energy efficiency in China?
- What will China's energy efficiency at the macro level be like in the future?
- How will China develop a low-carbon environment?

Y.-M. Wei and H. Liao, *Energy Economics: Energy Efficiency in China*,
DOI 10.1007/978-3-319-44631-8_10

10.1 Historic Opportunities for China's Energy Efficiency Improvement

The next two decades will be the key period in which to improve energy efficiency in China. The country will be faced with opportunities as well as severe challenges. If China can seize the key historical opportunities, make the best of market mechanisms and proper macro management, mobilize its initiatives, become a leader in facilitating social power, and act to improve energy efficiency, then it will discover the road to low energy consumption and high efficiency. Sustainable and stable economic growth provides the foundation and financial security for these measures. China is a developing country. Apart from some evident advantages, such as a great potential for economic development, relatively broad spectrum for structural adjustments, rapid pace of technological progress, rapid urbanization, and initially entering the renewal phase of its domestic consumption structure, there are also some advantages that other countries do not have, such as a great potential for energy savings in the technology market, notable scale-economy effects, and so on. Its external environment, as a whole, is advantageous as well. Peace, development, and cooperation have become the trends of our times. The economic globalization trend is developing both quickly and extensively. Global production factors flow easily between countries and industry transfers are speeding up. Moreover, global climate change is accelerating the progress of international cooperation in terms of energy and the environment. With domestic standards of living rising, close attention will be paid toward the people's health and environmental protection. All of the above matters represent China's opportunities to greatly improve the country's energy efficiency.

10.1.1 Solid Foundation for Energy Conservation Provided by Sustainable and Steady Economic Growth

Sustainable and steady economic growth has provided a solid foundation for providing energy-saving capital, enhancing energy-saving inputs, and alleviating social contradictions, which may emerge in the process of saving energy. Ameliorating energy efficiency must be carried out and actively pursued in the economic development of society.

Saving energy requires the transformation of equipment and facilities in ways that society wants. We also need to improve the energy efficiency of new equipment and facilities and increase the investment in energy conservation research. All these activities need a great deal of capital. If we do not have guarantees for relatively abundant and sufficient funds, then it is difficult to put energy conservation in first place. Although capital is scarce in any time period, China's overall national power has evidently strengthened since the 1990s. National economic development provides a more solid capital foundation for ameliorating energy efficiency. In the future, it will be difficult to keep China's economic growth rate above 9 % per year, but a relatively high rate of growth is still possible.

10.1.2 Potential and Capacity to Realize Lower Energy Consumption Per Capita and Per Unit of GDP

Compared with developed countries, China' energy consumption per unit of GDP is very high. Most developed countries' economic development experience indicates that during the process, energy consumption per unit of GDP represents an inverse-U shape, which progresses upwards at first and then gradually declines after reaching a peak. The later a country's economy grows, the lower the peak of energy consumption per unit of GDP.

The developed countries' experience also indicates that in the economic development of each country, the energy consumption per unit of GDP does not change in the same way. In contrast, their experiences present great differences. According to the IEA (2006b) and our calculations, the changes in the energy consumption of the seven industrialized western countries from 1960 to 2004 are shown in Fig. 10.1. Italy's energy consumption per unit of GDP is always lower than that of the other six industrialized countries while that of the United States (US) and Canada is the highest. After reaching a certain level of economic development, the developed countries' energy consumption per unit of GDP began to decline. Italy, Japan, Germany, and France once reached the stage where their energy consumption per unit of GDP increased. However, when the energy consumption per unit of GDP reached $15,000, it began to decline. China has a huge space for economic growth. In the future, it is possible that its energy consumption per unit of GDP will be lower than that of present-day Japan and Europe.

The energy consumption per unit of GDP shows great differences and has different potentials to decrease further. Even though energy consumption per unit of GDP has some connection to a country's resource endowments in general, it is also

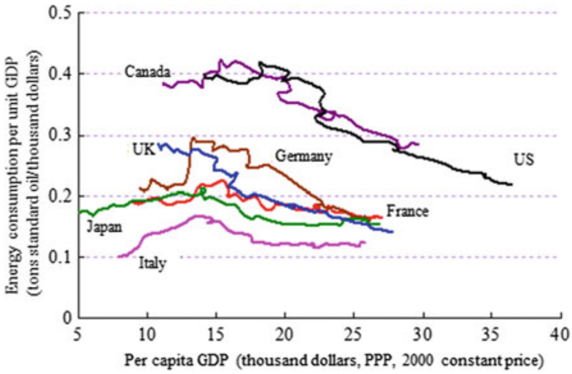

Fig. 10.1 Energy consumption per capita and per unit of GDP for the seven largest industrial countries. *Data sources* IEA (2006b) and authors' calculations

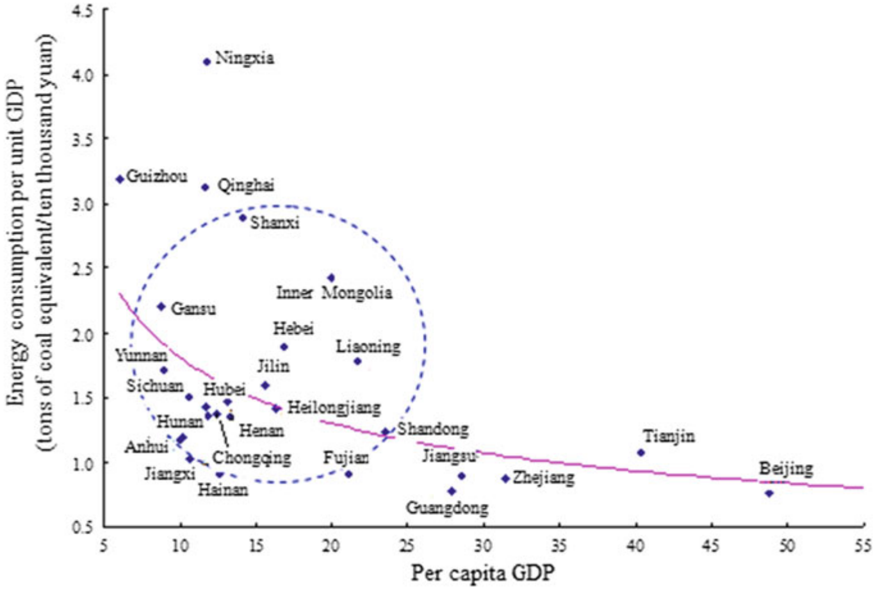

Fig. 10.2 GDP per capita and energy consumption per unit of GDP in different regions of China. *Data sources* NBS (2007) and authors' calculations

tied to the level of economic development. As Fig. 10.2 shows, according to NBS (2007) and our calculations, the higher the level of economic development in a region (indicated by per capita of GDP), the lower is the energy consumption per unit of GDP. For example, Beijing, Shanghai, Guangdong. Shandong, Henan, Hebei, Liaoning, Sichuan, Hubei, Hunan, Heilongjiang, Shanxi, and Inner Mongolia are regions that have a great potential for energy conservation. Ningxia, Guizhou, and Qinghai are also in the high-level category, but gross GDP in these regions gives less weight to the country as a whole and the potential for energy conservation is relatively small. With economic development, the level of energy consumption per unit of GDP in these regions may decrease to that of present-day Guangdong, Beijing, and Shanghai.

The development experiences of the antecedent industrialized countries indicate that the countries that are in the same phase or are closely aligned in terms of the level of economic development have great differences in energy consumption per capita. As Fig. 10.3 shows, according to the World Bank (2007) and our calculations, the GDP per capita in the US and Ireland were both close to $40,000 in 2004. But the energy consumption per capita in the US was twice that of Ireland. The GDP per capita for Canada, Japan, and UK was about $30,000, but the energy consumption in Canada was more than twice that of the UK and Japan. This shows that although the economic development levels are close, it does not mean that the energy consumption per capita is the same. Each country can still formulate a

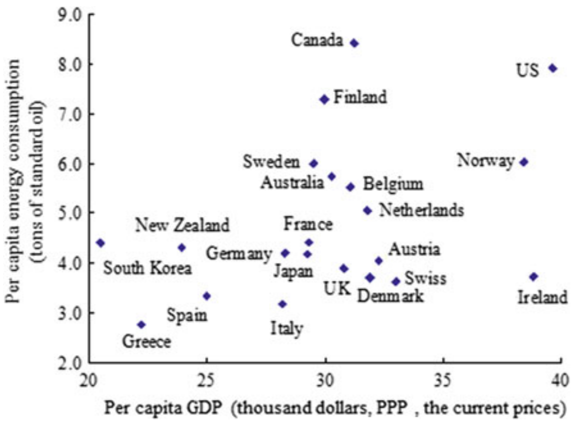

Fig. 10.3 GDP per capita and energy consumption per unit of GDP in some OECD countries. *Data sources* World Bank (2007) and authors' calculations

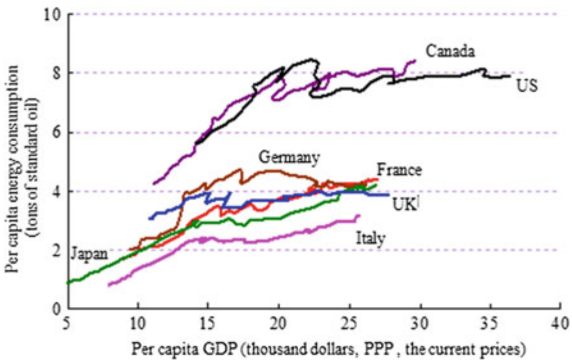

Fig. 10.4 GDP per capita and energy consumption per capita for the seven largest industrial countries. *Data sources* World Bank (2007) and authors' calculations

proper development strategy based on its national conditions and try to decrease its level of energy consumption per capita.

In the process of the developed countries' economic development, energy consumption per capita does not change in the same way. Rather, there are great differences. As Fig. 10.4 shows, according to the World Bank (2007) and our calculations and taking the seven largest industrial countries as an example, the energy consumption per capita in the US and Canada has always been higher than that in the other five countries (Germany, France, UK, Japan, and Italy) since 1960 and that in Italy has always been the lowest. When GDP per capita of Canada and the US reached \$230,000 (after the first oil crisis, energy consumption per capita appeared to slump), energy consumption per capita increased slowly. When the other five industrial countries' GDP per capita grew to \$180,000–\$220,000, the rate of increase in the energy consumption per capita began to slow down and even appeared to decline in some countries.

In general, the differences in the GDP per capita among the developed countries are decreasing. This presents an obvious narrowing trend. A country that has high

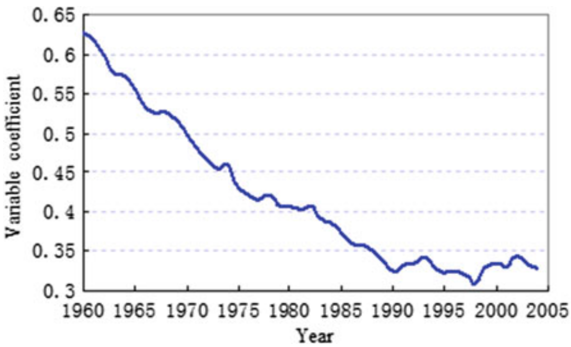

Fig. 10.5 The changing trend of OECD countries' energy consumption per unit of GDP. *Data sources* Authors' calculations

energy consumption per unit of GDP at the beginning declines quickly in terms of GDP per unit and its relatively late-mover advantage is more obvious than that in other countries. As Fig. 10.5 shows, in terms of energy consumption per unit of GDP, the coefficient of variation for the OECD countries decreases from 0.63 in 1960 to 0.33 in 2004, which indicates convergence.

Using quantitative analysis, we can also reach the same conclusion. The higher a country's energy consumption per unit of GDP in a given year (1960), the faster is the decrease in energy consumption per unit of GDP. This also indicates the obvious narrowing trend and late-coming advantages. The quantitative result is as follows:

$$\frac{1}{44}\ln\frac{E_T/GDP_T}{E_0/GDP_0} = -0.029 - 0.016\cdot\ln\frac{E_0}{GDP_0} \qquad (10.1)$$

$$(0.00) \quad (0.00)$$

$$R^2 = 0.760,\ \overline{R}^2 = 0.749,\ F = 72.65,\ D.W. = 2.52$$

(Note: The subscripts 0 and T represent 1960 and 2004 respectively; the values in parentheses are the p-value)

In conclusion, the energy consumption per unit of GDP for a country or region does not change in only one way. A country whose economy falls behind can conduct a proper strategy to produce late-mover advantages based on its own conditions and thus realize the least amount of energy consumption while promoting economic development. Saving energy and reducing energy intensities are restricted by the economic development phase in terms of industrialization and urbanization. However, there still exists room for some subjective improvements.

Since 1978, the change in China's energy consumption per unit of GDP has shown a downward trend in general. From 1978 to 2009, it decreased three-fourths in total. However, compared with the developed countries, the country's energy consumption per unit of GDP is still high. As long as we try to find a proper economic model that makes full use of the late-mover advantages and to make our economy develop in a highly energy-efficient way, such as finding a new industrialization process and shortening the middle phase of industrialization, then it will be possible to lower China's energy consumption per capita and per unit of GDP to below those for Japan and Italy in the past. While keeping a rapid economic development, our society can also realize a rapid decline in energy consumption per unit of GDP.

10.1.3 Numerous Areas for Energy Conservation Provided by Low Energy-Intensive Industries

10.1.3.1 Lowering Energy Intensity Benefits from Increases in the Proportion of Tertiary Industry

At present, the proportion of China's tertiary industry is low and increasing this proportion is favorable to reducing energy consumption. According to NBS (2010), China's value added in the tertiary industry still accounts for a small proportion of total GDP, which was 42.6 % in 2009. The value added per unit of GDP in the secondary industry was approximately four times that in the tertiary industry. If the secondary industry's proportion decreased by 1 % and the tertiary industry's proportion increased by 1 %, then the national energy consumption could be reduced by about 1 %. Today, the proportion of the value added in China's tertiary industry is much lower than the average level in the OECD countries, which was 70 % in 2008. Even compared with the developing countries such as India and Brazil, the proportion of value added for China's tertiary industry was also lower by approximately 13–15 %.

Even when comparing China with developed countries when they were at the same stage of industrialization, the proportion of our service industry is still relatively low. As Table 10.1 shows (MIC 2007), Japan's value added in its tertiary industry after the Second World War (1950s), when it was in the middle process of industrialization, represented 47 % of the country's GDP. With the continuation of the industrial process, the proportion still grew rather than declining. According to the OECD (2007), even though the proportion of Korea's industrial value added to its total GDP rose and reached a peak (44.3 %) in 1991 during the process of industrialization, the proportion of the tertiary industry's value added also rapidly increased, rising from 43.2 % in 1970 to 54.4 % in 2000, and the increase has continued thereafter (Table 10.2). According to the experiences of Korea and Japan, the proportion of China's tertiary industry to total GDP still has significant room to increase in the next 30 years (Table 10.3).

Table 10.1 Industrial structure of Japan after second war

	1955	1960	1965	1970	1975	1980	1985	1990	1995	2000	2005
Primary industry	19.2	12.8	9.5	5.9	5.3	3.5	3.1	2.4	1.8	1.7	1.4
Secondary industry	33.7	40.8	40.1	43.1	38.8	36.5	35.1	35.7	30.3	28.5	26.4
Tertiary industry	47.7	46.4	50.3	50.9	55.9	60.0	61.8	61.8	67.9	69.8	72.2

Table 10.2 Industrial structure during the process of industrialization of Korea

	1970	1975	1980	1985	1990	1995	2000	2007
Primary industry	27.2	25.2	15.1	12.7	8.5	6.1	4.8	3.0
Secondary industry	29.6	33.7	40.5	41.5	43.3	42.9	40.7	39.4
Tertiary industry	43.2	41.2	44.4	45.8	48.2	51.0	54.4	57.6

Producer services are an important part of the modern service industry. The manufacturing industry, which is closely related to producer services, is always the emerging industry that has high value added and low energy consumption. In 2006, the proportion of US producer services to total GDP was approximately 30 %. With the continuation of China's industrialization process, the increasing space for producer services is also large. Developing producer services during the industrialization process favors an acceleration of the industrialization process that shortens the process and reduces the total energy consumption.

10.1.3.2 Structural Adjustments Within Industry Related to Information Technology and Created by New Conditions for Saving Energy

At the beginning of the 21st century, China was in the late mid-industrialization phase. Steel, building materials, non-ferrous metals, chemicals, automobiles, machinery, and so on are energy-intensive industries that are growing quickly. Based on the developed countries' experiences, the later a country enters the middle phase of industrialization, the larger is its industrial structure adjustment space.

In contrast to the industrialized countries at the beginning of the 20th century, China's industrialization is being carried forward during the rapid development of Information and Communication Technology (ICT). In this context, we can choose to fight for broader industrial structure space. We can skip some laggard industries to realize a "great-leap-forward" development. For example, according to the data provided by the BEA (US Bureau of Economic Analysis), the US information industry's value added was only 1.67 % of GDP in 1950 and the electrical and electronic equipment manufacturing industry's value added was only 1.73 % of GDP. But now, China's proportions are approximately 3 and 6 %, respectively (on the basis of 2008 data), which shows an obvious late-mover advantage.

Since the 1990s, the technological revolution based on information and Internet technology has brought a great opportunity to improve China's economic development and industrial structure. Some emerging industries, which are based on information and communication technology, are always low energy consumers with high value added products. The data shows that the contributions that information and communication technology made to the US economy rose from 2.8 % in the 1948–1973 period to 17.8 % in the 1995–2002 period. The US total factor productivity increased from 5.0 to 66.2 % during the two respective periods (Jorgenson 2005).

Table 10.3 China's industrial structure in main years

Year	1955	1960	1965	1970	1975	1980	1985	1990	1995	2000	2005	2009
Primary industry	46.3	23.4	37.9	35.2	32.4	29.9	28.2	26.9	19.8	14.8	12.1	10.6
Secondary industry	24.4	44.5	35.1	40.5	45.7	48.2	42.9	41.3	47.2	45.9	47.4	46.8
# Industry	21.0	39.0	31.8	36.8	41.5	43.9	38.3	36.7	41.1	40.3	41.8	
Tertiary industry	29.3	32.1	27.0	24.3	21.9	21.9	28.9	31.8	33.0	39.3	40.5	42.6

Modern information technology is in favor of transforming traditional industries and realizing enterprise system energy savings. Modern enterprises' product work flows are complex. Optimizing the enterprises' energy systems, reducing energy waste, and enhancing energy recoverability rates cannot be realized only by the experiences of decision makers. Since the 1990s, the development of information technology has further promoted the transformation of corporate management. Advanced management ideas and tools such as Conventional Imaging Methods (CIMS), Enterprise Resource Planning (ERP), Supply Chain Management (SCM), and so on are widely available and popular in various enterprises, especially large- and medium-scale enterprises. Fixed assets, labor force, raw materials, and so on, as well as energy, are all involved in decision-making support systems. The enterprises' production and management flow systems continue to optimize and energy efficiency keeps going up. Reducing the product rejection ratios and improving the products' value added are also ways to save energy.

10.1.4 New Energy Conservation Opportunities Brought About by Industrial Structure Upgrading and International Technology Transfers Induced by Economic Globalization

The trend of economic globalization seriously promotes international technology transfers, which provide great opportunities for China to import and incorporate advanced energy-saving technology from abroad and give full play to the late-mover advantages. In the long-term process of industrialization, including technology research and development inputs, developed countries have designed and accumulated many energy conservation technologies. Every country is cooperating and participating in the exchange of energy conservation information and enhancing its energy efficiency in various ways. Actively importing, distributing, and using the developed countries' advanced energy conservation technology can narrow the gap between China's energy-intensive products (and their energy consumption per unit of product) and those of the developed countries. The developed countries' energy conservation management systems and mechanisms can also be used by China as a reference.

10.1.5 Broader Markets Facilitate Advanced Energy Conservation Technology

China is a developing country with a population of 1.3 billion people, in a period of industrialization and marketization and has a great market potential. It also has widely dispersed and ample space for advance energy-conservation technologies with obvious distributional effects, low costs per unit of production, and notable scale-economy effects. All the above represent our advantages that developed countries do not have. However, the developed countries have many advanced energy conservation technologies. However, because of such factors as small market scales and the influence of all kinds of interested parties, it is difficult to develop a large-scale promotional program, which, in turn, will further restrict the research and development of advanced energy conservation technology. Even though it is difficult to escape the heavy industrialization phase, it is possible to enhance the energy conservation technology. Advanced technology can not only be imported from foreign countries, it can also be researched and developed by ourselves. Seizing the historical opportunities and recognizing our huge market scales, China absolutely has the possibilities and resources to conduct the basis of that research and use the most advanced energy conservation technology in the world. Our energy conservation technology can have major breakthroughs and be widely distributed (including other developed countries), just like our technological advancement in the production of hybrid rice in the 20th century.

China needs a great deal of fixed capital during the process of industrialization and urbanization. In the future, the need for such equipment will increase rapidly and the market scales will be very large. These needs include all equipment that have a great potential for technological breakthroughs and market promotion prospects. If we can seize the opportunity that fixed capital is updated and transformed on a large scale, the energy-saving standards of fixed-capital investment are improved, and advanced energy conservation technology is encouraged, promoted, and applied, then an efficient and energy-saving capital stock level will be realized in the future.

Restrained by its resource endowments for a relatively long time, China's energy consumption structure is still focused on coal and this is likely to remain in the near future. The positive effects on energy conservation will depend on the various specializations and scale effects of production, promotion of transforming coal to electricity, and improvement in the final energy consumption structure. By 2030, we will need to install approximately 1.5 billion kW of electricity. During the 2008–2030 period, more than half of the existing generation equipment will be retired while the additional installed capacity will be approximately 1.2 billion kW of which approximately 850 million kW will be from thermal power generation. This represents a huge market for generation equipment. Therefore, advanced thermal power generation technology can be widely applied and distributed. If all of the new thermal power generation projects are supercritical and ultra-supercritical units, or IGCC (integrated gasification combined cycle) generating systems, then the country would realize high efficiency for its entire power generation network in the future. In 2005, China's coal equivalent consumption of its 6000 kW and above power generation plants was 343 g/kWh. If we consider the most advanced generation technology, then the equivalent coal consumption would drop to 270 g/kWh. Calculated in terms of the generation of 5000 billion kWh in 2030, the equivalent energy conservation would represent 365 million tce. Besides the great increase in the number of fixed capital projects, a great number of outdated high-energy consuming and high-pollution producing equipment will become obsolete.

In terms of consumption, China is in the updating phase of its residential consumption structure. In 2009, GDP per capita had already exceeded $3600 (according to the exchange rate in that year). Automobiles, houses, and air conditioners were widely purchased by families. If these consumption goods have comparatively low energy efficiencies but represent a great number of items, then residential energy consumption will greatly increase. If we can seize upon the key phase of updating the households' consumption structure and use policy instruments like strict energy conservation technology standards (e.g., accelerating the research of hybrid vehicles and promotional marketing measures), then we will greatly improve the energy efficiency levels of the households' durable consumer goods.

Even though China's energy efficiency will catch up to that of the developed countries in the future, there is still room to improve. According to the report entitled *Energy Technology Perspectives: Scenarios & Strategies to 2050*, published by the IEA (2006a), improving all energy efficiency technologies should be the top priority of even the developed countries because there is still much room to improve energy conservation in the construction, industry, and transportation sectors.

10.1.6 Energy Conservation Laws and Market Mechanisms Lead to Energy Efficiency Improvement

Energy conservation does not just refer to energy production and consumption; it is also one system of engineering that relates to the economic life of an entire society. We need to build a suitable system with appropriate mechanisms to provide system guarantees for energy conservation.

China has endorsed many laws and regulations and issued policy documents related to energy conservation. In 1997, China issued its *Energy Conservation Law* and made some progress. After nearly one decade, China's energy situation, economic system, and cultural environment have greatly changed. With the need to adjust the existing situation, the Standing Committee of the National People's Congress passed a revised *Energy Conservation Law* in October 2007, which further established and perfected its energy conservation system and mechanisms by changing government functions and the ways of energy conservation management. It also provided a legal basis for energy-saving incentives like further implementing measures in the areas of finance, revenues, prices, investments, government purchases, and so on. It is expected that China will further promote its *Energy Law* in 2010, which is the basic law in the energy field that favors the full-scale operation of an energy development strategy.

The service industry's development relies on sound legislation and a sound legal system, as well as impeccable market mechanisms. For a long time, energy conservation mechanisms were based on the market, such as energy management contracts, but they were voluntary and difficult to popularize. One important reason is that the energy conservation mechanisms were not perfect. Energy management aims to overcome the market obstacles of new energy conservation technologies, reduce information asymmetry, promote energy conservation in a professional manner, realize energy conservation measures during the process of industrialization, and provide consulting services for enterprises to carry-out energy conservation reforms. It can be predicted that with sound energy conservation rules of law and efforts to continue perfecting the energy conservation system and mechanisms, the energy conservation service industry will develop at a high speed.

As long as the energy conservation system and mechanisms are perfected in a step-by-step manner, then this process will continue to be led by the market and guided by government. As long as enterprises can reduce costs and increase benefits in the process of energy conservation, then it is possible that energy conservation will become a conscious activity of the market entities. Energy conservation is consistent with improving an entire society's economic efficiency. Energy conservation comes before further energy exploitation, which, in itself, can always gain more economic efficiency. There are many international organizations and specialists who regard energy conservation as *the world's fifth largest energy resource*, ranking along with coal, petroleum, natural gas, and nuclear energy. IEA research indicates that improving energy efficiency can decrease the investment demand for supplying energy (development) and that it is the cheapest, fastest, and most environment-friendly method to satisfy the world's energy demand. Compared with developing renewable energy resources, energy conservation could actually gain more benefits (IEA 2006a). According to our calculations, China's total energy consumption tax is 7.2 trillion RMB, which accounted for 23 % of GDP in 2008. If the country can decrease its energy consumption efficiently, then a great deal of the energy costs and the environmental pollution treatment costs can be saved, which, in itself, is a large amount of economic benefits.

Since 2008, China's economy has generally trended toward a full recovery. It is predicted that economic development will return to a comparably high rate within a few years. If the country can seize upon this opportunity by building energy systems and mechanisms and accelerating resource product price reforms, then the negative impacts caused by economic and social development will be alleviated.

10.1.7 Properly Upgrading the Residential Consumption Structure Can Reduce Energy Consumption Growth Rate

China's residential consumption structure has entered the upgrading period. Household consumption has begun to transform from a focus on food and clothing to houses, automobiles, air conditioners, refrigerators, computers, and so on. These products consume a lot of energy during their lifecycles. If the government can publish related energy efficiency standards or evaluation systems and strictly execute them before households purchase energy-consuming goods on a large scale and greatly improve these products' energy efficiency, then it will be possible to realize high energy efficiency consumption by households in the future. If the product energy efficiency standards or evaluation systems are enacted after households have already purchased a significant number of low energy-efficiency products, then it will be difficult to transform the system.

Taking the residents' power consumption per capita in different regions as an example, the higher the economic development level, the higher is the residents' power consumption per capita. With the improvement in the economic development levels of the relatively backward areas, household energy consumption will also greatly increase. If all of the household appliances in these regions have high energy efficiencies, then we can save a great amount of energy when acquiring energy services.

In the process of upgrading the residential consumption structure, it is also necessary to guide the households to consume in a reasonable manner, strengthen energy conservation education, enhance the savings consciousness of society as a whole, create a conservation-minded social atmosphere, and avoid or decrease the high energy consumption trend; for example, helping to make the residents' housing demands reasonable, encouraging people to take public transportation, and so on. Whether or not we can seize the strategic opportunities of upgrading the residential consumption structure is very important if we are to realize the goal of decreasing energy consumption; that is, because the residential consumption structure stimulates production.

The next two decades represent China's opportunity to greatly reduce its energy intensity. If we do not take effective actions and miss this opportunity and do not radically change our economic growth pattern, as well as the high-energy consumption of our fixed capital and durable consumer goods, then China will be locked into developing a high-energy consumer economy and society and have more difficulty in lowering its energy consumption with terrible consequences. After entering the 21st century, China's urbanization process has accelerated and its residential consumption structure has begun to be upgraded. The opportunities to decrease our energy consumption are declining and the timeframe is narrowing.

10.2 Prospects of Energy Efficiency in Developed Countries and in China

10.2.1 Potential for Realizing Lower Energy Consumption Per Capita in China

Based on data from the World Bank (2008) and our computations, we obtained the OECD's real GDP per capita and energy consumption per unit of GDP in 2005. As shown in Fig. 10.6, even if the countries are close in terms of their level of economic development and similar in terms of their geographic latitude, their unit

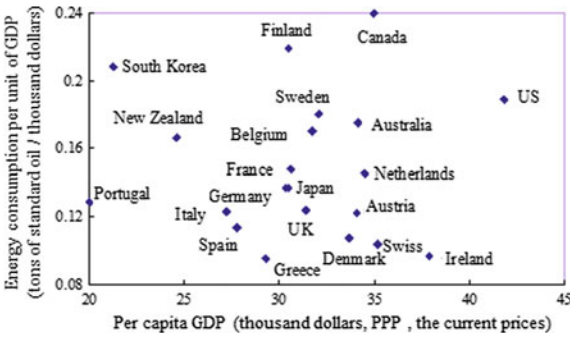

Fig. 10.6 OECD countries' energy consumption per capita and per unit of GDP (2005). *Data source* World Bank (2008)

energy consumption still displays wide differences. In 2005, the real GDP per capita gap between the US and Ireland was not very large, but the energy consumption per unit of GDP in the US was twice that in Ireland. The real GDP per capita in Canada, Japan, and UK was approximately $29,000, but Canada's energy consumption per unit of GDP was twice that in Japan and UK. This proves that all countries should formulate their own development strategy based on their own situation to maintain low energy consumption per unit of GDP along with a high economic development level.

10.2.2 Possibility of Realizing Lower Energy Consumption Per Unit of GDP in China

Based on data from the World Bank (2008) and our calculations, we determined the changes in the energy consumption per unit of GDP for the main developed countries since 1960 (for historical reasons, we do not include Germany in Fig. 10.7). From 1960 to 1970, the main developed countries' energy consumption per unit of GDP remained constant, with the exception of Italy, which greatly

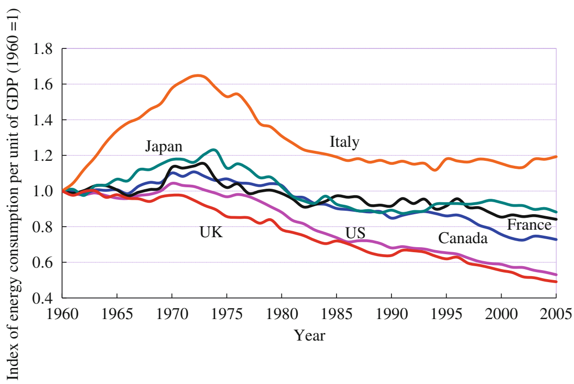

Fig. 10.7 Changes of energy consumption per unit of GDP in main developed countries (1960–2005)

increased. But after 1975, the main developed countries' energy consumption per unit of GDP declined quickly (except for Italy after 1990). However, some countries with the same GDP per capita had different energy consumption per unit of GDP.

From 2003 to 2004, China experienced an increase in energy consumption per unit of GDP. Since 2007, the rising trend has reversed. Considering China's current development level, it is equivalent to that in the US in 1960 and those in the five largest industrial countries (except Canada) in the period from 1970 to 1980 (Liao 2008). Therefore, by considering the late-mover advantages, China's energy consumption per unit of GDP can be reduced at a faster pace by trying hard.

10.2.3 *Potential for Gaining a Faster Decline of Energy Macro-efficiency*

For the OECD countries during different time periods (1960–2005, 1970–2005, 1980–2005, and 1990–2005), the β-astringency test of energy consumption per unit of GDP also indicates that every country's energy consumption per unit of GDP has obvious astringency traits (Liao 2008), as shown in Table 10.4. The countries with high energy consumption per unit of GDP at the beginning experience a greater rate of decline in energy consumption over time. At present, China's energy consumption per unit of GDP is relatively high (even though it is difficult to define how much higher than the developed countries), but by trying hard, we can continue to reduce the rate of energy consumption at a relatively fast pace.

10.2.4 *China's Energy Macro-efficiency Prospects*

Because of the differences in its development structure, it is difficult to make China's historical development phase exactly correspond to the developed countries

Table 10.4 OECD countries' β-astringency test of energy consumption per unit of GDP

Period	1960–2005		1970–2005		1980–2005		1990–2005	
Method	OLS	WLS	OLS	WLS	OLS	WLS	OLS	WLS
Intercept	3.057	2.880	3.896	3.705	4.430	4.161	4.033	3.906
	(0.284)	(0.273)	(0.364)	(0.357)	(0.584)	(0.526)	(0.853)	(0.780)
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
$\ln(e_m)$	1.616	1.522	1.973	1.861	2.164	2.012	1.807	1.766
	(0.135)	(0.131)	(0.196)	(0.199)	(0.335)	(0.307)	(0.494)	(0.454)
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.001]	[0.001]
R^2	0.848	0.835	0.783	0.765	0.649	0.644	0.302	0.334

when using a value index. From the perspective of energy macro-efficiency, China is currently at the level of the US in 1960 and the UK, France, Germany, Japan, and Italy in the period from 1970 to 1980 (Liao 2008). By comparing the developed counties' energy consumption per unit of GDP and timing sequences, as well as considering our astringency research, we believe that China's energy consumption per unit of GDP has much room to decrease in the future. In the next 30 years, China's energy needs relative to its GDP elasticity coefficient will possibly remain at approximately 0.6. But to realize this target, we still need to make significant efforts. To transform the great increase in energy consumption and change the development mode, the Chinese government and society have made great efforts, at great expense, since 2006 toward saving energy and reducing consumption to reduce energy consumption per unit of GDP by 20 % and reach the goal of the Eleventh Five-Year Plan.

In the last 30 years, China's economy has increased at the rate of 10 % per year. If China's economic growth rate is 8 % per year from 2010 to 2020, then its energy consumption per unit of GDP will be reduced by approximately 40 % from 2005 to 2020, as calculated using the energy elasticity coefficient of 0.6. In this situation and considering the growth in the proportion of renewable energy sources and natural gas, it can be predicted that carbon emissions per unit of GDP will also decrease 40 % (according to the presumed accuracy of the domestic energy statistics). The relevant sensitivity analysis is shown in Table 10.5. From the table, we find that if the economic growth rate and energy elasticity coefficient are 9.0 % and 0.7, respectively, then the energy consumption per unit of GDP will decrease 37 % from 2005 to 2020. Even though China has the possibility to decrease its carbon emissions per unit of GDP by 40–45 % (calculated according to the requirement that energy conservation's contribution is above 85 % and the energy consumption per unit of GDP is reduced by 38 %), it still needs to make significant efforts and spend a significant amount of money to make this happen.

Table 10.5 Sensitivity analysis of China's energy consumption per unit of GDP

Average annual growth rate of GDP	Energy demand elasticity	Cumulative decline of energy consumption per GDP (%)	
		2010–2020	2005–2020
8.0	0.6	26.0	40.0
8.0	0.7	20.1	35.3
9.0	0.6	28.5	42.1
9.0	0.7	22.2	37.0
9.5	0.6	29.8	43.1
9.5	0.7	23.2	37.8

10.3 Paths Leading to China's Low-Carbon Development

In recent years, energy consumption has increased rapidly by the dramatic growth in the economy. As a result, the emission of greenhouse gases has increased at the same scale and the per capita amounts have surpassed the world-average levels. In the future, we face more pressure in reducing greenhouse gas emissions. To deal with global climate change and achieve sustainable development, it is crucial that we develop in a low-carbon mode.

In fact, the authorities realized the importance of low-carbon development a long time ago. For instance, the Eleventh Five-Year Plan demanded that energy consumption per unit of GDP decrease 20 % and emissions of main pollutants decrease 10 %. These demands have both strengthened the government's responsibility and commitment to the people, reflecting China's strong will to make a great difference in the way the economy grows. Similarly, at the United Nations Climate Change Conference (COP15) before 2009, the authorities promised the world that CO_2 emissions per unit of GDP would be reduced 40–50 % by 2020 compared with that in 2005. Therefore, it is urgent that we find a proper way to develop a low-carbon economy in line with China's characteristics.

(1) Strengthen low-carbon development strategies and policies and formulate low-carbon development plans

The key to developing a low-carbon economy is technology and the core goals are to save energy and optimize the energy structure, which seems to be a simple objective but it is quite complicated. The reasons are as follows: to develop a low-carbon economy, one should not only include the production and consumption of the energy sectors but also consider the energy-intensive sectors. Moreover, we should not only pay close attention to the emissions but also care about the costs and impacts of the low-carbon technology. Furthermore, both short-term and long-term interests should be considered.

So how can we construct a low-carbon economy according to comprehensive, balanced, and sustainable development with China's characteristics? We need to strengthen our low-carbon development strategies and policies. Experts and scholars from the social, economic, and technological fields should participate together to avoid and reduce the negative impacts of different strategies. Decision makers need to conduct multi-level and multi-angle discussions and arguments, make choices after comparing the different programs, and then execute the related policies.

Low-carbon development includes every facet of the industrial chain—from production to consumption—and involves almost all sectors of the economy. That is why strategic, global short-term and long-term plans and their various combinations need be formulated, along with China's unique characteristics, to develop a low-carbon economy. Meanwhile, the government's power regarding macroeconomic regulations and control needs to be fully exerted.

(2) Based on energy savings, accelerate the optimization and upgrading of the industrial structure

Today, 84 % of global CO_2 emissions are from petroleum combustion and 65 % of greenhouse gas emissions are from fossil energy consumption, so saving energy and optimizing the industrial structure are the best ways to realize low-carbon development. China has done a good job in promoting renewable energy development and saving energy and such an achievement is notable. According to a global investment in sustainable energy trend report issued by the United Nations Environment Program in June 2009, China had become the "Green economic giant" in Asia. China's investment in renewable energy was more than $15.6 billion in 2008, representing an 18 % increase from 2007 and ranking first in the Asia-Pacific region. According to preliminarily data, in the first four years of the "Eleventh Five-Year Plan" plan, the energy consumption per unit of GDP declined a total of 15.6 % and was expected to total 19 % by 2010. The goal in the "Eleventh Five-Year Plan" plan was that the energy consumption per unit of GDP would decline by 20 %. In the current institutional framework, China has to determine the target for the decline in the energy consumption per unit of GDP during "TEN-TWO-FIVE" plan and include this target in the national economic and social development plans. It was pointed out earlier that the contribution of energy savings to the energy-efficiency improvements is more than 85 % of the target for the decline of carbon intensity from 2005 to 2020 (further notices to ensure the realization of the "Eleventh Five" emission reduction targets were issued by the State Council on May 4, 2010). For this reason, China should first integrate the concept of low-carbon development into improving energy efficiency, optimizing the energy structure, and upgrading the industrial structure. Second, the authorities should advocate "green" development and spare no effort in constructing a low-carbon, cyclic, and eco-friendly economy; hence, achieving harmonious and sustainable development.

(3) Encourage independent innovations of low-carbon technology and refine the system through research and development

At present, China's low-carbon economic development includes high costs, relatively outdated technology, unsound legal norms, and imperfect market functions. So shaping the low-carbon technology system through independent innovations and research is the key to developing a low-carbon economy. In recent times, many countries (e.g., China, European countries, US, Japan, Brazil, and India) have strengthened their support of energy conservation, new energy resources, and renewable energy and greatly promoted the development of low-carbon technology, especially in Europe and the US. Finding a low-carbon development path with Chinese characteristics is far from being realized when only importing, distributing, and applying foreign advanced technology. China must also encourage independent innovations, research advanced technologies with independent intellectual property, shape a technology system with low-carbon research and development, and realize harmony among the various technologies.

At the same time, China's low-carbon technology development plan and technology standards should be researched and proposed. Uniform technology standards are the key to promising a technology system and industrial chain that operates with high efficiency. They are also the key in promoting technology research and extending the scope of production and consumption with high efficiencies and low emissions. In addition, building a diverse low-carbon technology system of energy conservation, clean coal, new energy sources, renewable energy sources, and carbon sequestration technology in a step-wise fashion is also important. All these measures are designed to provide strong technology support for transforming the energy consumption structure and optimizing the industrial structure.

(4) Promote reasonable low-carbon production and consumption ideas and build a low-carbon consumption model for society as a whole

A public consumption model always precedes the market's value, which eventually shapes an economic development model that is suited to its needs. Low carbon consumption reflects the ideas and preferences of consumers, and only the leading producers and consumers are able to transform it into a habit or value that becomes a low-carbon consumption model for society as a whole. As a result of a lack of reasonable leaders in terms of the process of consumption, we form many bad consumption habits, such as excessive consumption, one-off consumption, and so on, which brings serious waste and pollution to the economic environment. Therefore, when developing a low-carbon economy, one must attach some importance to the aspects of production and consumption. Low-carbon production and low-carbon consumption are both important. At present, many people's consumption ideas are still at the level of luxury consumption. Take private cars as an example. Many people still believe that high emissions and luxury items represent dignity, which is totally different from most people in Japan and many countries in Europe. If we do not change our consumption ideas, then low-carbon development may only be a fantasy.

Low-carbon development is not only the responsibility of the administrative authorities or the various enterprises, it also needs the participation of society as a whole. The concept of low carbon should be integrated into every aspect of social development—from buildings and the design of the production process flows to the choice of raw materials, types of production, packaging, transportation, and consumption. Every link in the production chain should advocate low-carbon consumption. Behaviors such as turning off lights when leaving a room, setting reasonable air conditioner temperatures, reducing the use of elevators, purchasing low-emission automobiles, choosing public transportation, and using reusable bags are becoming conscious activities for many people, providing a good foundation for developing a low-carbon consumption model for society as a whole.

(5) Strengthen international cooperation and raise the overall importance of low-carbon industries
A low-carbon economy is a new kind of economic development model. Some developed countries in Europe started relatively early in terms of low-carbon development. Europe has the biggest and most active carbon market (EU ETS), the earliest and most "free-carbon community" (BedZED housing development in London), and the earliest and most mature carbon tax policy (Finland and Denmark). At the same time, these countries have mastered many advanced renewable energy sources and new energy utilization technologies, as well as carbon emission reduction technologies. So in the aspects of low-carbon technology, carbon markets, carbon tax policy, and carbon emissions management, all these countries have accumulated many experiences. Therefore, we should only realize the rapid development of China's economy and society by strengthening international cooperation; learning from the European countries' low-carbon development concepts, models, technologies, and experience; and actively combining China's practices with designing long-term mechanisms for low-carbon development and promoting a comprehensive low-carbon industry.

References

IEA (2006a) Energy technology perspectives: scenarios and strategies to 2050. International Energy Agency (IEA), Paris

IEA (2006b) World energy statistics and balances, 2006th edn. International Energy Agency (IEA), Paris

Jorgenson DW (2005) Chapter 10 accounting for growth in the information age. Handb Econ Growth 1(A):743–815

Liao H (2008) Study on econometric model of energy efficiency and its application. Dissertation, Chinese Academy of Sciences

Ministry of International Affairs, Communications (2007) Statistical handbook of Japan 2007. Statistics Bureau, Statistical Research, Training Institute, Ministry of International Affairs, Communications, Tokyo

National Bureau of Statistics (2007) China statistical yearbook 2007. China Statistics Press, Beijing

National Bureau of Statistics (2010) China statistical abstract 2010. China Statistics Press, Beijing

OECD (2007) OECD Database

World Bank (2007) World development indicators 2007. World Bank, Washington DC

World Bank (2008) World development indicators 2008. World Bank, Washington DC