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ENHANCING ENERGY EFFICIENCY IN CHINA: ASSESSMENT OF SECTORAL POTENTIALS

CHINA ENERGY EFFICIENCY SERIES

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JUNE 2017

EDITED BY

Zhiyu Tian
Energy Research Institute, National Development and Reform Commission

Xiliang Zhang
Tsinghua University, Beijing

Xianli Zhu
Copenhagen Centre on Energy Efficiency, UNEP DTU Partnership, Copenhagen

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Magnum Custom Publishing, New Delhi

Copenhagen Centre on Energy Efficiency
UNEP DTU Partnership
Marmorvej 51
2100 Copenhagen Ø
Denmark
Phone: +45 4533 5301
www.energyefficiencycentre.org
Email: c2e2@dtu.dk

This book can be downloaded from www.energyefficiencycentre.org

Please use the following reference when quoting this publication:

Tian, Z., Zhang X., Zhu X. (Eds.) (2017)

Enhancing Energy efficiency in China: Assessment of sectoral potentials

Copenhagen: Copenhagen Centre on Energy Efficiency, UNEP DTU Partnership.

ISBN: 978-87-93458-16-1

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FOREWORD

Improving energy efficiency is critical to achieving the ambitious goals of the Paris Agreement under the UN Framework Convention on Climate Change. Most global and regional studies show that enhanced energy efficiency policies and actions can dramatically reduce energy use and associated greenhouse gas emissions. This is reflected in the fact that 167 countries included action on enhanced energy efficiency in the Intended Nationally Determined Contributions they submitted as the foundation for the Paris Agreement.

Energy efficiency delivers not only reductions in energy consumption and emissions, if implemented properly, it will also provide opportunities for many economy-wide benefits, such as improved health and well-being, cleaner air and more jobs.

In spite of the political ambition and potential for deriving multiple benefits from action, there are many common barriers and market failures that often prevent countries from moving at the expected pace in implementing the actions on energy efficiency that have been identified. Many of these barriers and failures need to be overcome in by individual countries and cities, but best practice examples of proven solutions are extremely useful in showing what works and how it can be made to happen. This report presents an analysis of energy-efficiency opportunities and actions in a number of key sectors in China aimed at inspiring other countries. The assessment highlights some of the conditions for success that will be essential for replication in other parts of the world.

In terms of the future growth of energy and related greenhouse gas emissions, China and India stand out from other countries due to their rapid economic development, large populations, rapid urbanization and growing industrial sectors. Both countries are focused on decoupling both energy use and emissions from economic growth. In their Intended Nationally Determined Contributions, submitted under the Paris Agreement, both countries have included strategies to pursue improved energy efficiency across the main sectors of their economies.

This report is part of the China and India Energy Efficiency series that has emerged from the High Impact Opportunities studies that the UNEP DTU Partnership has supported in China and India. In China, the study was carried out by the Energy Research Institute under the National Development and Reform Commission and the Institute of Energy, Environment and Economy at Tsinghua Institute. The other two reports published on China are under the study: *Best Practice and Success Stories on Energy Efficiency in China*, and *High Impact Opportunities for Energy Efficiency in China*. All the reports can be downloaded for free at www.energyefficencycentre.org.

China is the second-largest economy in the world and the biggest greenhouse gas emitter. Whether it can continue the rapid improvements to its energy efficiency, and how, are critical not only to fulfilling the country's international climate targets and domestic five-year plan targets, but also key to realizing the global goals of climate change and clean and sustainable energy development.

This report, *Enhancing Energy Efficiency in China: Assessment of Sectoral Potentials*, uses energy and economic models to assess the potential for further energy-efficient improvements in the transport, building, industry and power sectors. The report starts with a modelling assessment of the role of energy efficiency in supporting China to achieve its Intended Nationally Determined Contribution (INDC) of reaching a peak in its greenhouse gas (GHG) emissions by around 2030. It concludes that the contribution of improvements in energy efficiency to China reducing its GHG emissions is between 67% and 80%, depending on whether the country reaches this peak in 2025, 2030, or 2035. The report continues to use the Long-Range Energy Alternatives Planning (LEAP) model to assess the potential for improvements in energy efficiency in the four key sectors.

For each sector, the study identifies key high-impact opportunities (HIOs) for improvements in energy efficiency, some technical, others structural. The technical HIOs are those based on specific technological improvements, such as more energy-efficient housing and more fuel-efficient cars. The structural HIOs involve changes in product mix and service mix, such as reducing the overcapacity in energy-intensive industries and increasing the use of public transit for passenger transport. Moreover, for each sector, the report also identifies barriers to the realization of the HIOs and offers a set of recommendations for how to address them.

I would like to thank the national experts and practitioners who have contributed the eight best practice and success stories included in this publication. I am sure that the publication will be of value to policy-makers, practitioners and researchers in the two countries, as well as providing inspiration to other countries on how to move forward with energy-efficiency policies and action paving the way to further gains in efficiency.

John Christensen
Director
UNEP DTU Partnership

ACKNOWLEDGEMENT

We thank the authors of the different chapters for their insightful contributions. We appreciate the inputs received from Surabhi Goswami and Mette Annelie Rasmussen on the layout design. We would also like to thank Robert Parkin for proof-reading the English language in this publication. Finally, we would like to thank the Copenhagen Centre on Energy Efficiency for providing the opportunity to undertake the study

Zhiyu Tian
Xiliang Zhang
Xianli Zhu

LIST OF ABBREVIATIONS

3D	3-dimentional
ADB	Asian Development Bank
BEV	Battery electric vehicles
BRT	Bus rapid transit
C2E2	Copenhagen Centre on Energy Efficiency
CAFV	Corporate average fuel consumption
CBRC	China Banking Regulatory Commission
CCPP	Combined cycle power plant
CCHP	Combined cooling, heating and power
C-GEM	China-in-Global Energy Model
CGE	Computable general equilibrium
CHP	Combined heat and power
CO2	Carbon Dioxide
ERI	Energy Research Institute of the National Development and Reform Commission
EU	European Union
EV	Electric vehicles
FIRR	Financial internal rate of return
FYP	Five-year Plan
GEA	German Energy Agency
GDP	Gross Domestic Product
GT	Gigaton
GW	Gigawatts
HIO	High Impact Opportunities
HEV	Hydrogen fuel battery vehicles
HTHP	High temperature and high pressure
ICE	Internal combustion engines
IEC SCENARIO	Intensified Energy Conservation Scenario
IEA	International Energy Agency
INDC	Intended Nationally Determined Contribution
KGCE	Kilogram coal equivalent
KV	Kilovolts
KWH	Kilowatt-hour
L/KM	Liter/kilometer
LCD	Liquid crystal display
LEAP	Long-Range Economy Alternatives planning model
LNG	Liquefied natural gas
LPG	Liquefied petroleum gas
M2	Square meter
MOHURD	Ministry of Housing and Urban-Rural Development
MTCE	million ton carbon equivalent
MW	million Watt
NDRC	National Development and Reform Commission
NGCC	Natural gas combined cycle
NGOA	National Government Offices Administration
NOX	Nitrogen oxides
OLED	Organic light emitting diode
PHEV	Plug-in hybrid electric vehicles
PM	Particulate matter
PV	Photovoltaics
RMB	Renminbi
SAM	Social accounting matrix
SO2	Sulfur dioxide
THUBERC	Building Energy Research Centre, Tsinghua University
US$	US dollars
USA	United States of America
VAT	Value-added tax
WB	World Bank

EXECUTIVE SUMMARY

Supported by the UNEP and the Copenhagen Centre on Energy Efficiency (C2E2), Tsinghua University and the Energy Research Institute (ERI) of the National Development and Reform Commission jointly conducted a research project on high-impact energy efficiency opportunities. Based on a review of progress in energy conservation across China during the 12th Five-year Plan (FYP) period and assumptions about future macro-economic development, industrial structure upgrading and energy conservation technological improvement trends, the research group adopted the method of quantitative analyses, using the LEAP model (Long-Range Energy Alternatives Planning model) and C-CGE (China - Global Energy) model to analyze the role of energy conservation in achieving China's international climate pledges for 2030. It also sought to provide detailed insights into the high impact opportunities for energy efficiency across industry and the building, transportation and power sectors under both the reference scenario and the intensified energy-saving scenario. By conducting a comparative analysis and a sensitivity analysis of the two scenarios, the research group identified future high impact energy-efficiency opportunities from both technical and structural angles. Lastly, policy recommendations were provided for technical and systematic obstacles in the popularization process of the High Impact Opportunities (HIOs). During the project execution period, the research group employed multiple methods such as a literature review, field investigations and expert interviews to provide a scientific and reliable model analysis.

Energy efficiency and energy conservation have been a long-term priority for China, bringing about multiple benefits, including the maximum utilization of energy resources, improving environmental quality and ensuring energy security. Since 2006 the Chinese government has set mandatory targets to cut energy intensity per unit of GDP in its economic and social development plans, with strong legal measures, regulatory policies and financial incentives being put in place. By 2015, energy use per unit of GDP declined by 18.4% compare to that in 2010, far exceeding the established target of 16% in the 12th FYP. From 2010 to 2015, energy efficiency and conservation have allowed China to avoid the equivalent of 865 megatonnes of coal equivalent (Mtce) of energy use, equivalent to a reduction of 1.82 gigatonnes (Gt) in CO_2 emissions. Efforts in energy efficiency and conservation in China have contributed a lot to the global sustainable transformation, accounting for more than half of the world's entire energy savings in the past thirty years.

Being the world's largest developing country, China currently finds itself in a rapid development stage involving extensive industrialization and urbanization and is faced with multiple challenges such as economic transformation, environmental protection and tackling climate change. In 2015, China released its Intended Nationally Determined Contribution (INDC), which promised that China's CO_2 emissions will peak in around 2030, that China will strive to reach this peak value as early as possible, that CO_2 emissions per unit of GDP will decline by 60% to 65% against the 2005 level, and that the proportion of non-fossil energy in China's primary energy consumption will reach about 20% by 2030. Energy efficiency is one of the most important solutions for climate change mitigation. To achieve its voluntary targets by 2030, China needs to adopt further energy efficiency and emission-reduction policies and measures on the basis of previous experience. Our modeling results show that China could achieve its INDCs targets by intensifying its energy conservation and low-carbon transformation efforts. Compared to the reference scenario, carbon emissions in 2030 have to be 15% lower if China is peak its greenhouse gas emissions around 2030. Under the intensified energy-saving scenario, carbon emissions in 2030 could be 27% lower compared to the reference scenario. Energy efficiency and conservation played a vital role in both scenarios in achieving the climate pledge, contributing about three quarters of total emission reductions.

This report focuses on the role of energy efficiency and conservation in realizing the CO_2 emissions reductions under the intensified energy-saving scenario. We define energy efficiency and conservation as any action that reduces energy demand through the improved use of materials and better energy efficiency or through structural shifts from energy-intensive activities to more service-oriented activities. Through the LEAP model-based quantitative analysis, this report identified 26 HIOs in the industrial, building, transportation and power sectors, of which sixteen are technical HIOs and ten structural ones. Given the joint effects of technical improvements and economic structure optimization, these HIOs could realize energy savings of over two Gtce in 2050.

Based on key criteria for HIO selection, the research group, after calculation and discussion, selected six key HIOs from the sixteen technical HIOs in the industrial, building, transportation and power sectors. Of the six HIOs chosen, one belongs to the industrial sector: industrial waste heat recovery and utilization technology, which is estimated to save an energy amount of about 200 Mtce in 2050; two belong to the building sector: passive building and air source heat pump, which are estimated to save an energy amount of 220 Mtce and 50 Mtce respectively in 2050; another two belong to the transportation sector: improvement of fuel economy of trucks and

promotion of electric vehicles, which are estimated to save an energy amount of 45.94 Mtce and 49.22 Mtce respectively in 2050; and the last one belongs to the power sector: transformation of coal-fired power plants, which is estimated to save an energy amount of 56 Mtce in 2050. For the key energy-intensive sectors, the main findings are summarized as follows.

Under the intensified energy-saving scenario, energy consumption in the industrial sector is expected to peak from 2015 to 2020 and to be halved in 2050, compared to the reference scenario. Four technical and three structural HIOs will result in an energy saving of over 1 billion tce in 2050. The selected technical HIOs included industrial waste heat recovery technology, advanced industrial combustion/calcination technology, high-efficiency and environment-friendly industrial boiler, and raw material route-based process adjustment and energy use optimization. It is estimated that in 2050, the four technical HIOs will produce an energy saving of 580 Mtce, of which nearly 200 Mtce through industrial waste heat recovery technology. The structural HIOs included the 'de-capacity' and transformation development of energy-intensive industries, the industrial 'eco-link' development mode and a subversive industrial production technical revolution. In 2050, the three structural HIOs are estimated to save an energy amount of about 500 Mtce, of which nearly 200 Mtce will saved by 'de-capacity'. In order to realize the above HIOs, we need to widen the channels for enterprises to acquire information and application about examples of energy-saving technologies, improve standard systems related to energy-saving production processes, technologies and equipment, remove system and mechanism barriers across departments and industries, and establish an institutional environment that is favorable to the optimization and upgrading of industrial structure and to the improvement of industrial competitiveness.

Under the intensified energy-saving scenario, energy consumption in the building sector is expected to peak around 2039 and be restricted to below 750 Mtce in 2050. Four technical HIOs and one structural HIO will contribute energy savings of over 700 Mtce in 2050. Energy savings in the building sector will mainly be produced by technical HIOs including promoting passive housing, popularizing high energy efficient equipment, carrying out deep energy conservation retrofit to existing buildings, and using low-grade industrial waste heat for heating. The first three HIOs will contribute energy savings of 220 Mtce, 200 Mtce and 120 Mtce respectively in 2050. The structural HIO is mainly about promoting building industrialization. Energy savings in 2050 will stand at 30 Mtce. Moreover, building industrialization can save materials, indirectly lowering the energy consumption of the industrial sector. To realize the above HIOs, it is necessary to strengthen capacity building to promote passive housing, tighten the minimum requirements regarding energy-efficiency standards of appliances, conduct deep energy-conservation retrofitting for existing buildings, and reinforce planning for using industrial waste heat to heat cities and towns.

Under the intensified energy-saving scenario, energy consumption in the transportation sector is expected to peak around 2035. Four technical and three structural HIOs will contribute energy savings of 650 Mtce. Technical HIOs include upgrading the fuel economy of trucks, improving the fuel economy of light-duty passenger vehicles, developing and popularizing battery electric and plug-in hybrid electric vehicles, and enhancing electrification of the railways. In 2050, energy savings from the above HIOs will stand at 45.94 Mtce, 12.39 Mtce, 49.22 Mtce and 11.28 Mtce respectively. Structural HIOs include improving the share ratio of public transport, improving the proportion of railway use and promoting vehicle sharing. In 2050, energy savings from the above HIOs will stand at 14.85 Mtce, 8.06 Mtce and 0.3 Mtce respectively. To seize the above HIOs, we need to boost the transformation and upgrading of transportation sector management, quicken the pace of the reform of railway marketization, periodically release and update fuel economy standards in a timely fashion, expedite the construction, investment and financing of public transport infrastructure, and continue with R&D and the promotion of advanced technology in the transportation field.

Under the intensified energy-saving scenario, energy consumption in the power sector will peak around 2030. Four technical and three structural HIOs will contribute energy savings of 340 Mtce in 2050. Technical HIOs in this sector include the transformation of pure condensing steam turbine units to realize cogeneration, comprehensive energy-conservation transformation technology for coal-fired power plants, the adoption of high-capacity and high-parameter coal-fired generation units for newly built units, and the implementation of power grid energy-saving technological transformations. Structural HIOs include accelerating the development of renewable energy power generation, promoting the scale development of nuclear power and developing natural gas power generation. The biggest fossil-fuel energy-saving potential in the power sector under the intensified energy-saving scenario in 2050 comes from the substitution of fossil energy by renewable energy and nuclear power for power generation and heating, which can save energy by 248 Mtce; improvements to the power generation efficiency of thermal power units can contribute energy savings of 56 Mtce; the popularization of cogeneration can contribute 32 Mtce in energy savings; and improvements to power grid efficiency will contribute 15 Mtce in energy

savings. To seize the above HIOs, we need to encourage cogeneration promotion according to local circumstances, encourage coal-fired power plants to improve power-generation efficiency, explore new-generation high-performance and low-cost power-generation technologies, boost energy conservation transformation and renewable energy absorption of power grids, and speed up power system reforms.

CHAPTER 1

ROLE OF ENERGY CONSERVATION IN ACHIEVING CHINA'S CLIMATE PLEDGE

Yuyan WENG
Xiliang ZHANG
Sheng ZHOU

China announced its Intended Nationally Determined Contribution (INDC) target before the United Nations Climate Conference in Paris in 2015. In the INDC, China committed to peak its CO_2 emissions around 2030 and making best efforts to peak it early. In achieving this target, China intends to lower its CO_2 emissions per unit of Gross Domestic Product (GDP) by 60% to 65% from the 2005 level, and increase the share of non-fossil fuels in its primary energy consumption to around 20% by 2030. In order to fulfil these commitments, China's energy and economic systems need to undergo a deep low-carbon transition. This chapter focuses on the quantitative analysis of the transition pathway toward a low-carbon energy economy under different scenarios by deploying the China - Global Energy Model (C-GEM), and examining the role of energy conservation in achieving China's climate pledge.

1.1 SCENARIOS

It is necessary to look back the history of the carbon intensity and energy intensity of China's GDP during the past three decades before talking about low-carbon transitions in order to analyze the relationship between economic growth, energy consumption and CO_2 emissions, and then to design appropriate scenarios accordingly.

1.1.1 THE HISTORY OF CHINA'S CARBON INTENSITY OF ITS GDP

The core of the transition toward a low-carbon energy economy is to improve carbon productivity, which can be measured by average annual reduction rates of carbon emissions per unit of GDP. In the past thirty years, China's energy intensity and carbon intensity have both achieved substantial reductions. Since 1980, the Chinese economy's carbon intensity has declined by 4.9% per year due to improvements in labor productivity and the development of energy-saving technologies. However, after 2000, the energy-saving efforts started to be offset by the boom in heavy industries and the increase in the proportion of industry in the economy, resulting in a rise in carbon intensity instead of a fall. After 2005, the central government significantly intensified its reduction measures and introduced various new policies for effective energy-saving and emission reduction. The energy efficiency has been further improved and the average annual reduction rate of carbon intensity reached almost 5% in the decade thereafter (China National Bureau of Statistics, 2015) (see Figure 1-1).

1.1.2 SCENARIO DESCRIPTION

Three scenarios are designed in this study to reflect different levels of policy effort: a Reference Scenario, a 2030

FIGURE 1-1. Changes in China's carbon intensity of GDP, energy intensity of GDP, and carbon intensity of energy during 1980-2015

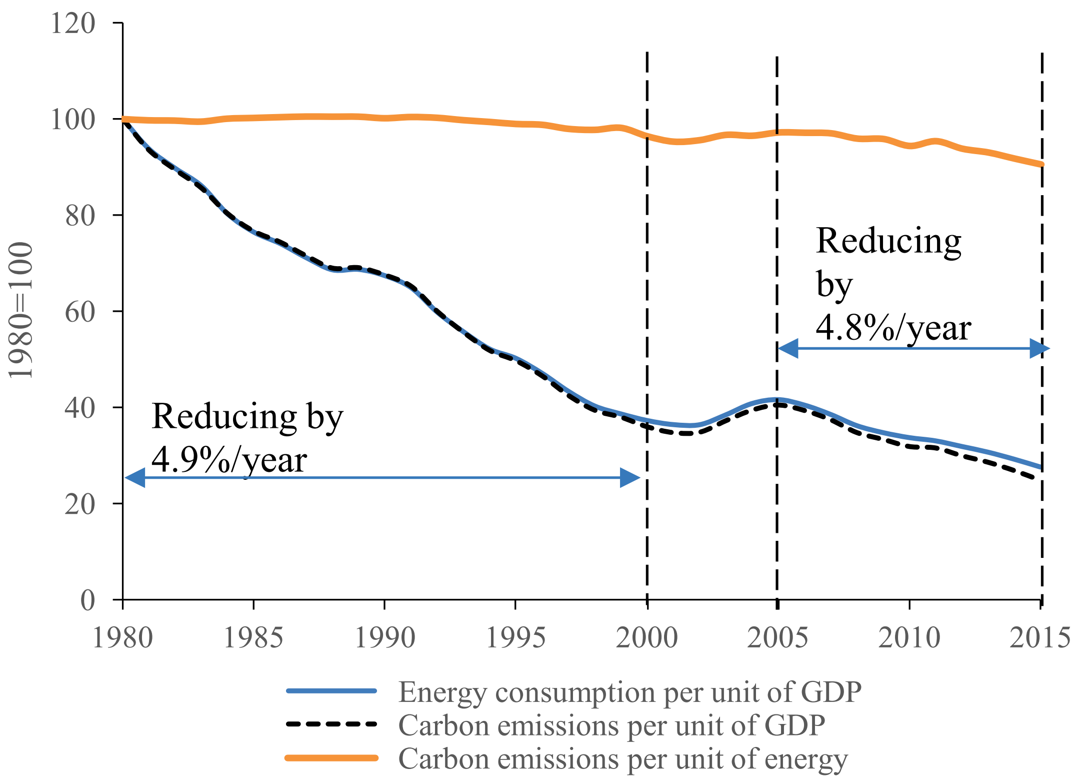


TABLE 1-1. Policy description of the Reference Scenario, 2030 Peak CO_2 Scenario and 2025 Peak CO_2 Scenario

	REFERENCE SCENARIO	2030 PEAK CO_2 SCENARIO	2025 PEAK CO_2 SCENARIO
I. Low-Carbon Energy System Transformation Targets			
Carbon Intensity	3% reduction per annum after 2015	4% reduction per annum after 2015	5% reduction per annum after 2015
II. Policies			
Carbon price mechanism	The intensity reduction targets are imposed using a carbon price mechanism, and the price is derived endogenously.		
Gas subsidy	Encouraging the development of natural gas and subsidizing its use.		
Feed-in tariff for wind, solar and biomass electricity	Subsidizing renewable energy on top of the current benchmark grid-connection tariff for coal-fired power plants through a renewable energy surcharge imposed on electricity consumption.		

Peak CO_2 Scenario and a 2025 Peak CO_2 Scenario. The Reference Scenario targets at a 3% per year reduction in carbon intensity, the 2030 peak CO_2 scenario at a 4% per year reduction, and the 2025 Peak CO_2 Scenario by a 5% per year reduction.

These carbon intensity reduction targets are imposed in each scenario using a carbon price mechanism, and the price of carbon emissions is derived endogenously in the model. In addition, we simulate other supporting mechanisms in the model. For example, natural gas is subsidized in order to increase the production and supply of it and a Feed-in tariff mechanism is exploited to expand the development of renewable energy such as wind, solar and biomass electricity.

Brief descriptions of the Reference Scenario, 2030 Peak CO_2 Scenario and 2025 Peak CO_2 Scenario are shown in Table 1-1.

1.2 MODEL AND MACROECONOMIC ASSUMPTIONS

1.2.1 CHINA-IN-GLOBAL ENERGY MODEL (C-GEM)

(1) Overview

The China-in-Global Energy Model (C-GEM) is a multiregional, multi-sector, recursive-dynamic, computable general equilibrium (CGE) model of the global economy. The model is one of the major analytical tools developed by the China Energy and Climate Project (CECP), a cooperative effort of the Massachusetts Institute of Technology's (MIT) Joint Program on the Science and Policy of Global Change and the Tsinghua Institute of Energy, Environment, and Economy. The primary goal of the model is to analyze the impact of existing and proposed energy and climate polices in China on technology, inter-fuel competition, the environment and the economy within a global context.

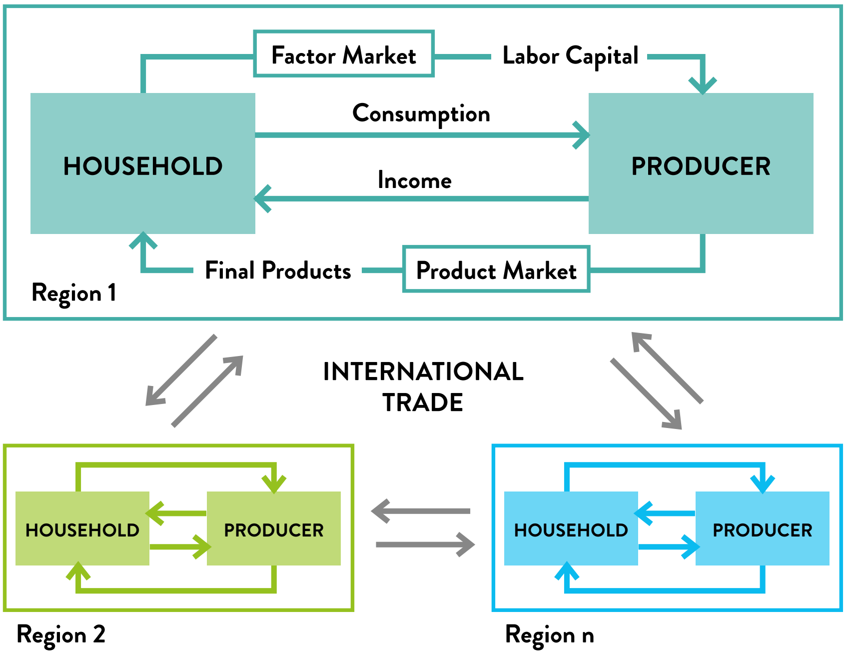
The C-GEM is a computable general equilibrium (CGE) model with supplemental accounting for energy and emissions quantities. Its basis structure derives from the Walrasian General Equilibrium Theory formalized by Arrow and Debreu (Arrow and Debreu, 1954; also Sue Wing, 2004). A key advantage of the CGE framework is its ability to capture policy impact across the interlinked sectors of the economy, including interactions with goods and factor markets and bilateral trade relationships between regions. CGE models are now well-established tools used to undertake quantitative analysis of the economic impacts of energy and environmental policies (Böhringer et al., 2003; Sue Wing, 2004).

The CGE model simulates the circular flow of goods and services in the economy, as shown below.

The arrows in Figure 1-2 show the flow of goods and services in the economic system in each world region. Companies (producers) purchase factor inputs (such as labor, capital and land) from factor markets and intermediate goods and services from product markets, which they then use to produce final goods and services. Consumers (households) purchase these final goods from the product markets and sell their labor, capital and other resources in the factor markets to obtain an income. In each region, the producers maximize profits given input costs, and consumers maximize their utility while being subject to a budgetary constraint. Relative prices are adjusted endogenously to maintain equilibrium across product and factor markets.

Households allocate income to private consumption and savings with substitution across these two categories as defined by the consumer utility function. In the recursive-dynamic model framework, the household savings decision is based only on current period variables. Households in the C-GEM are assumed to be homogenous, so that one representative household in each region owns all

FIGURE 1-2. Economy-wide circular flow of goods and services in the C-GEM



the factors of production and receives all the factor payments. Tax is imposed in almost all transactions as specified in the base year data and is collected by government.

Savings and taxes raise fund for investment and government expenditure. The government in the C-GEM is modeled as a passive entity that collects tax revenues and recycles money to households in the form of a lump-sum supplement to their income from factor returns (Sue Wing, 2004). The government's expenditure in each region is fully funded by households. Different regions are linked to international trade in that their products can be exported to the rest of the world, and imported goods are also sold in the domestic product market following the Armington Assumption (Armington, 1969). In the C-GEM, international trade is limited to the product market; factors such as labor and endowments are not mobile across regions. The international capital flows that account for the trade imbalances between regions in the base year are assumed to gradually disappear.

(2) Model structure

The C-GEM disaggregates the world into 19 regions and 21 sectors, as shown in Table 1-2 and Figure 1-3 below.

We aggregate the C-GEM regions on the basis of economic structural similarities, membership in trade blocs and geographical relationships. The regional aggregates can be separated into two distinct groups, namely developed economies and developing economies, according to the definitions used by the International Monetary Fund (IMF, 2012). The major developed economies (United States, European Union, Japan, Canada, Australia) and major developing countries (China, India, Russia, Brazil, South Africa), as well as major oil suppliers (mainly the Middle East) are explicitly represented. We further disaggregate the major economies around China, including South Korea, Japan and Southeast Asia's developing countries, as well as developed Asia, as individual regions in the C-GEM.

Production in each of the 19 regions in the C-GEM is comprised of 21 production sectors. This aggregation includes a detailed representation of the energy production sectors and the energy intensive industries. As shown in Table 1-3 below, five energy production sectors (coal, crude oil, natural gas, refined oil, and electricity), and four energy-intensive sectors (non-metallic mineral products, iron and steel, non-ferrous metals products, and chemical rubber products) are described in detail.

As a multiregional CGE model, the C-GEM is parameterized and calibrated based on a balanced social accounting matrix (SAM). The SAM is an array of input-output accounts that quantifies the flow of goods and services in the benchmark period (Sue Wing, 2004). The C-GEM is based on the latest version of the Global Trade Analysis Project database (GTAP 9) and China's official economy and energy data set (Narayanan et al., 2012). It is also formulated and solved as a Mixed Complementarity Problem (MCP) using MPSGE, the Mathematical Programming Subsystem for General Equilibrium (Mathiesen, 1985; Rutherford, 1999), and the Generalized Algebraic Modeling System (GAMS) mathematical modeling

TABLE 1-2. Definition of regions in the C-GEM

REGIONS IN THE C-GEM	DETAILED COUNTRIES AND REGIONS INCLUDED
Developed Economies	
United States (USA)	United States of America
Canada (CAN)	Canada
Japan (JPN)	Japan
South Korea (KOR)	South Korea
Developed Asia (DEA)	Hong Kong, Taiwan, Singapore
Europe Union (EUR)	Includes EU-28 plus Countries of the European Free Trade Area (Switzerland, Norway, Iceland)
Australia-New Zealand (ANZ)	Australia, New Zealand, and rest of the world (Antarctica, Bouvet Island, British Indian Ocean Territory, French Southern Territories)
Developing and Undeveloped Economies	
China (CHN)	Chinese mainland
India (IND)	India
Developing Southeast Asia (SEA)	Indonesia, Malaysia, Philippines, Thailand, Vietnam, Cambodia, Laos, rest of Southeast Asia.
Rest of Asia (ROA)	Rest of Asia countries
Mexico (MEX)	Mexico
Middle East (MES)	Iran, United Arab Emirates, Bahrain, Israel, Kuwait, Oman, Qatar, Saudi Arabia
South Africa (ZAF)	South Africa
Rest of Africa (AFR)	Rest of Africa countries
Russia (RUS)	Russia
Rest of Europe (ROE)	Albania, Croatia, Belarus, Ukraine, Armenia, Azerbaijan, Georgia, Turkey, Kazakhstan, Kyrgyzstan, rest of Europe.
Brazil (BRA)	Brazil
Latin America (LAM)	Rest of Latin America countries

FIGURE 1-3. Regions in the C-GEM

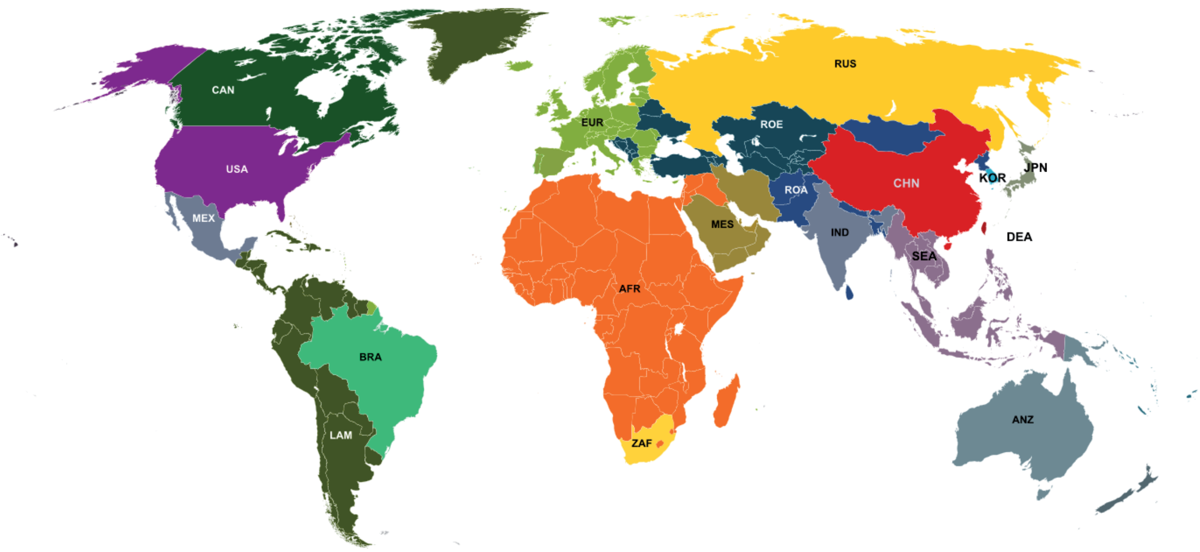


TABLE 1-3. Descriptions of the 21 sectors in the C-GEM

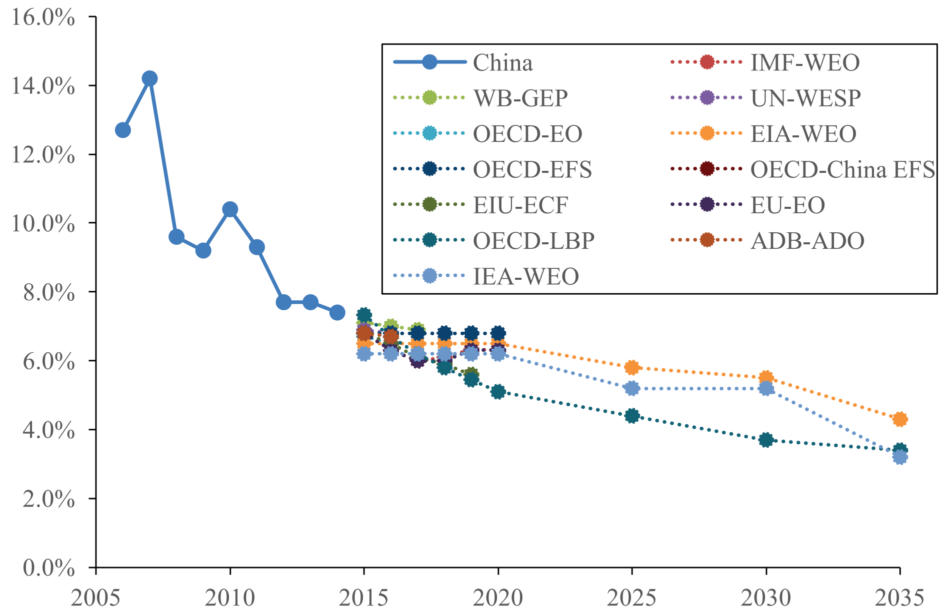
TYPE	SECTOR	DESCRIPTION
Agriculture	Agriculture (AGR)	Crops, forest, livestock
Energy Sectors	Coal (COAL)	Mining and assemblages of hard coal, lignite and peat
	Oil (OIL)	Extraction of petroleum
	Gas (GAS)	Extraction of natural gas
	Petroleum Product (ROIL)	Refined oil and petro chemistry product
	Electricity (ELEC)	Electricity production, collection and distribution
Energy-Intensive Industry	Non-Metallic Minerals Products (NMM)	Cement, plaster, lime, gravel, concrete
	Iron and Steel (I_S)	Manufacture and casting of basic iron and steel
	Non-Ferrous Metals Products (NFM)	Production and casting of copper, aluminum, zinc, lead, gold, and silver
	Chemical Rubber Products (CRP)	Basic chemicals, other chemical products, rubber and plastic products
Other Industries	Food and Tobacco (FOOD)	Manufacture of foods and tobacco
	Mining (MINE)	Mining of metal ores, uranium, gems. other mining and quarrying
	Construction (CNS)	Building houses factories offices and roads
	Electronic Equipment (ELE)	Electronic equipment
	Textile (TWL)	Textiles, wearing apparel and leather products
	Transport Equipment (TEQ)	Transport equipment
	Other Machinery (OME)	Other machinery
	Other industries (OTHR)	Other industries
Service	Transportation Services (TRAN)	Water, air and land transport, pipeline transport
	Commercial and Public Services (SER)	Commercial and public services
	Dwelling (DWE)	Dwelling

that is consumption-based and driven by the creation of value.

Based on a different understanding of the prospects for China's future reforms, the international community has different expectations of China's recent economic growth. The International Monetary Fund (IMF, 2015) gave a pessimistic forecast for China's economic growth of 6.3% in 2016, because of the difficulties in China's transition to a new growth model. Relatively upbeat forecasts from the World Bank (WB, 2015), on the other hand, assumed that China's economy will grow by 6.9% in 2017. The Asian Development Bank (ADB, 2015) forecast 6.7% growth for 2016 in its 'Asian Development Outlook 2015 update'. The United Nations (UN, 2015a) expected China's growth rate to be 6.8% in 2016. In its International Energy Outlook, the Energy Information Administration's (EIA, 2014) assumption of China's GDP annual growth was 6.5% in 2015-2020. The International Energy Agency (IEA, 2016) assumed China's economic growth rate to be 6.2% in 2015-2020 in 'World Energy Outlook 2016'. The European Union (EU, 2015) predicted 6.3% for the same period. The Organization for Economic Cooperation and Development expected in its 'Economic Outlook: Long-term Baseline Projections' (OECD, 2014) that China's economy would grow by 6.7% in 2016 and 6.2% in 2017, probably falling to 5.1% in 2020. A comparison of these expectations is summarized in Figure 1-4.

Most of the growth forecasts are only short-term, research on the medium- and long-term growth of China's economy being covered less. The Energy Information Administration, in its 'International Energy Outlook', assumed China's economic growth to be 5.8% in 2020-2025, 5.5% in 2025-2030 and 4.3% in 2030-2035 (EIA, 2014). The International Energy Agency in its 'World Energy Outlook 2016' forecast economic growth in China to be 5.2% annually in 2020-2030 and 3.2% in 2030-2040 (IEA, 2016). The Organization for Economic Cooperation and Development has conducted detailed research on the growth factors for China's medium- and long-term economic growth, including population growth, employment rate

FIGURE 1-4. Forecasts of China's economic growth rate in the literature



and total factor productivity, concluding that China's economic growth rate in 2020-2025 would be 4.4%, 3.7% in 2025-2030 and 3.4% in 2030-2035 (OECD, 2014), as shown in Figure 1-4 (ADB, 2015; EIA, 2014; EIU, 2015; EU, 2015; IEA, 2016; IMF, 2015; OECD, 2014; OECD, 2015; OECD, 2016a; OECD, 2016b; WB, 2015; UN, 2015a).

1.2.3 SOCIAL AND ECONOMIC DEVELOPMENT ASSUMPTIONS

(1) Economic growth

Based on the forecasts in the literature and by research groups, we design a scenario for future economic growth for China, set out in Table 1-4. The annual growth rate during the '13th Five-year Plan' is 6.5%, which is in agreement with the central government's strategic plan. The assumptions for GDP growth rate after 2020 are all within the range of the expectations expressed in the literature.

TABLE 1-4. GDP growth rate assumptions for China in the C-GEM

	2015-2020	2020-2025	2025-2030	2030-2035
GDP Annual Growth Rate	6.5%	5.8%	4.8%	3.8%

(2) ECONOMIC STRUCTURE

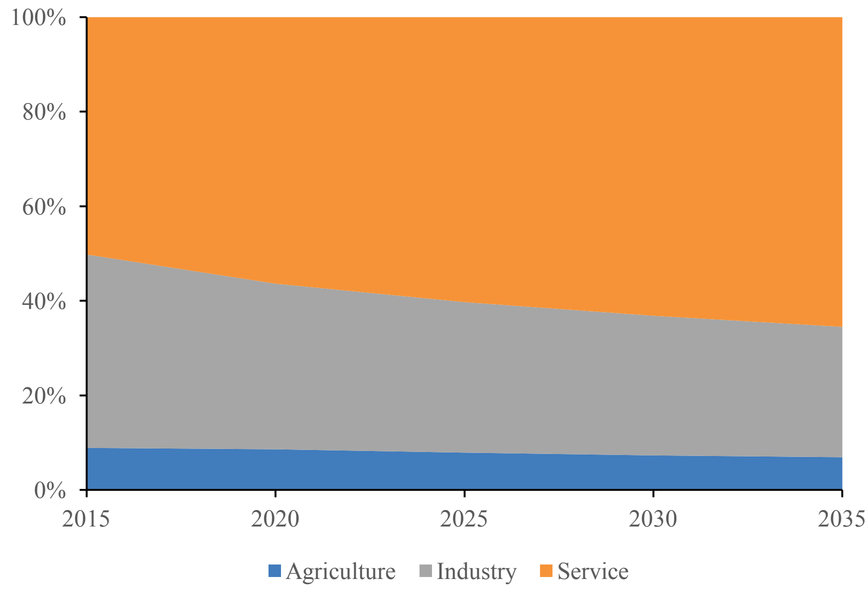
China's economic development has entered the 'New Normal' in the context of the low-carbon transition, characterized by the transformation of its development mode from investment-driven growth to intensive growth driven by consumption and innovation, with significant changes in economic structure. With social development and incomes rising, the proportions of primary and secondary industries in GDP tend to decline, and the proportion of the tertiary industry tends to increase, while industry's internal structure will change from the low side to the high side by achieving industrial upgrading.

Therefore, we made some basic assumptions about China's future economic structure. We calibrated China's future mode of consumption, especially the respective shares of agriculture, food and services in total consumption with reference to the proportion of final consumption in total spending by major countries in the world. Similar to the consumption mode, we also calibrated China's investment structure and the input-and-output structures of major sectors such as iron and steel, machinery, transportation and so on. The assumptions regarding China's economic structure are shown in Figure 1-5.

(3) Population growth

The population values are assigned using the World Population Prospects of the United Nations (UN, 2015b), as shown in Figure 1-6. According to this projection, much of this growth will happen in developing regions such as Africa and India. The population of Africa is also projected to grow rapidly and is estimated to double between 2010 and 2040. India is projected to surpass China in population to become the world's most populous country between 2020 and 2025. China's population is predicted to peak at around 1.4 billion around 2030.

FIGURE 1-5. Assumptions about China's economic structure



1.3 RESULTS AND DISCUSSION

1.3.1 PRIMARY ENERGY CONSUMPTION

(1) Total primary energy consumption

Our analysis shows a remarkable change in the trend of primary energy consumption under these three scenarios. Under the reference scenario, China's primary energy consumption will keep increasing from 4.3 gigatonnes of coal equivalent (Gtce) in 2015 to 7.4 Gtce in 2035. Under the 2030 peak CO_2 scenario, the primary energy consumptions are 5.1 Gtce in 2020 and 6.2 Gtce in 2030. Total primary energy consumption in the 2025 peak CO_2 scenario will see a greater decline at 4.9 Gtce in 2020 and 5.6 Gtce in 2030. In 2030, total primary energy consumption under the 2025 peak CO_2 scenario will be 10% less than that under the 2030 peak CO_2 scenario and 18% less than that in the reference scenario, as shown in Figure 1-7.

(2) Energy mix

Turning to the energy mix, in the reference scenario, the proportions of coal, oil, gas and non-fossil fuels in primary energy consumption in 2030 will be 55%, 18%, 10% and 17% respectively. In the 2030 Peak CO_2 Scenario, the average annual reduction rate of carbon intensity maintains

FIGURE 1-6. World population projections from the United Nations

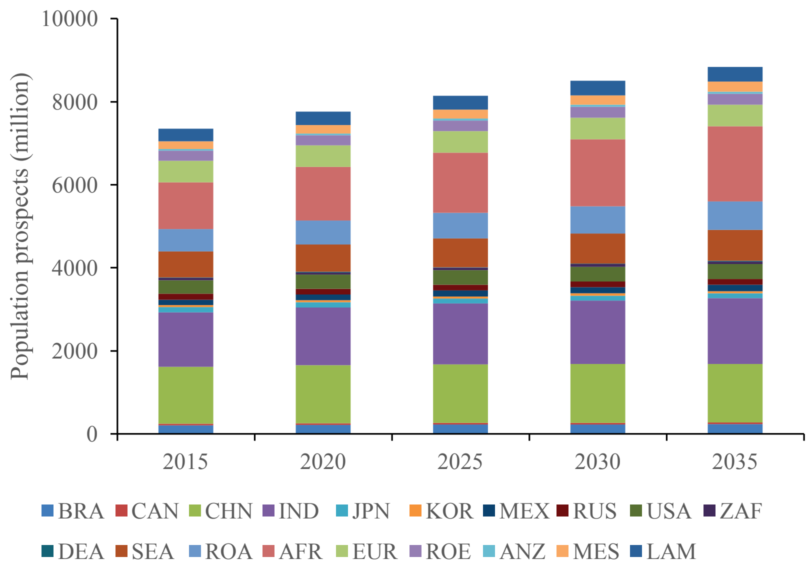
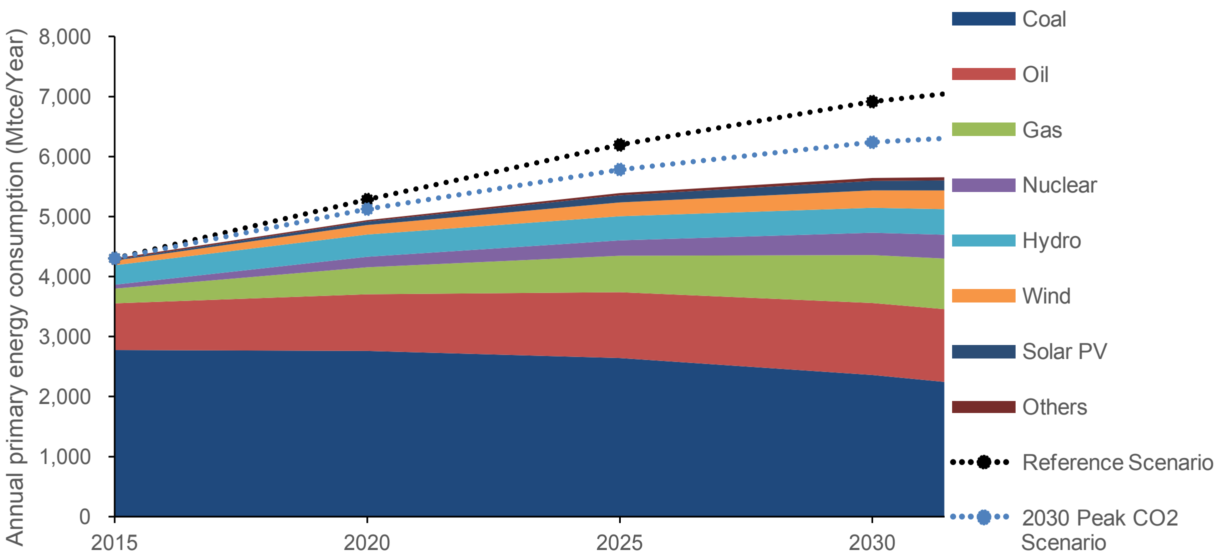


FIGURE 1-7. Primary energy consumption in China under different scenarios



a level of 4% from 2015 through 2035. A higher carbon price results in a greater reduction of coal use and more rapid growth of non-fossil fuel utilization. Under this scenario, the proportions of coal, oil, gas and non-fossil fuels in primary energy consumption in 2030 will change to 49%, 20%, 12% and 20% respectively. With a stricter policy in the 2025 Peak CO_2 Scenario, where carbon intensity maintains reductions of 5% from 2015 to 2035, an increasing carbon price results in a greater reduction in coal use and booming development for non-fossil fuels. In 2030, coal, oil, gas and non-fossil fuels in primary energy consumption will account for 42%, 21%, 14% and 23% respectively. It should be noted that under this scenario coal consumption will no longer increase anymore and decline thereafter, which means that coal use will reach its peak during the '13th Five-year Plan' (2015-2020).

1.3.2 CARBON DIOXIDE EMISSIONS TRAJECTORY

Shown in Figure 1-8 are the trajectories of CO_2 emissions from fossil fuel consumption under the three scenarios during 2010-2035. Under the reference scenario, China's CO_2 emissions will keep increasing from 8.1 Gt in 2010 to 13.8 Gt in 2035. Under the 2030 Peak CO_2 Scenario, however, emissions will peak in 2030 at approximately 11.4 Gt and begin to decline thereafter. Under the 2025 Peak CO_2 Scenario, where the carbon intensity reduction rate is 5% per year from 2015 to 2035, carbon emissions will peak in 2025, and the peak will be even less - around 10.0 Gt, as shown in Figure 1-8.

1.3.3 THE CONTRIBUTION OF ENERGY CONSERVATION

According to the model results and analysis, under the reference scenario, the average contribution of energy conservation to emissions reduction during 2015-2035 could reach 80%, while the role of energy substitution is only 20%. Under the 2030 Peak CO_2 Scenario, energy conservation could contribute about 76% of the total amount of emissions reduction, with 24% by energy substitution. Under the 2025 Peak CO_2 Scenario, energy conservation's contribution to emissions reduction decreases to 72%, and energy substitution's role increases to 28%, as shown in Figure 1-9. From the time perspective, taking the 2025 Peak CO_2 Scenario as an example, the contribution of energy conservation decreases from 75% to 67%, though the role of energy substitution grows from 25% to 33%, as shown in Figure 1-10.

Thus it can be seen that, compared to energy substitution, energy conservation plays a more important role in the field of energy saving and emissions reduction than in the past, while energy substitution has a tendency to increase its impact with the growing strength of transformation and over time. China's low-carbon transition in its energy economy needs to rely on technological improvements, energy efficiency enhancements and energy mix transformations, that is, when considered from the energy-conservation and energy-substitution perspectives.

FIGURE 1-8. Carbon dioxide emissions trajectories in China under different scenarios

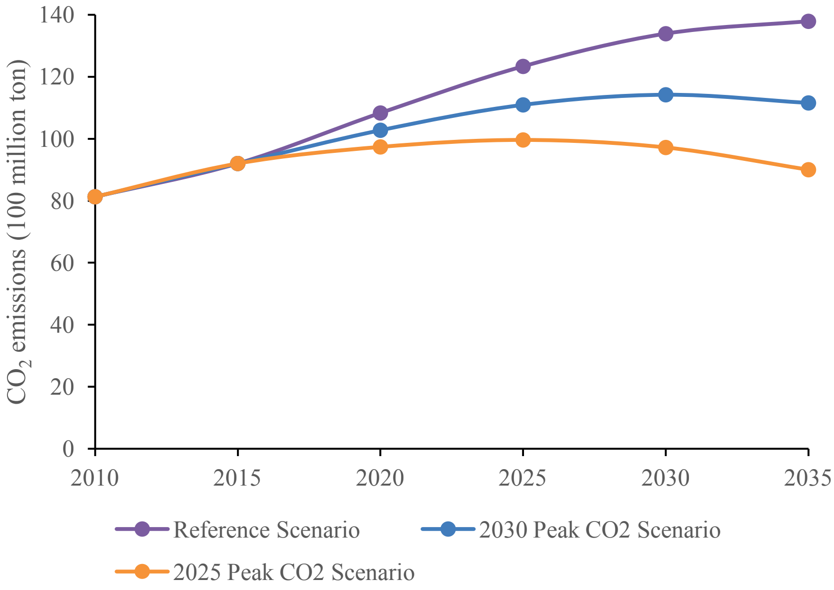


FIGURE 1-9. The contribution of energy conservation and energy substitution to emissions reduction under different scenarios

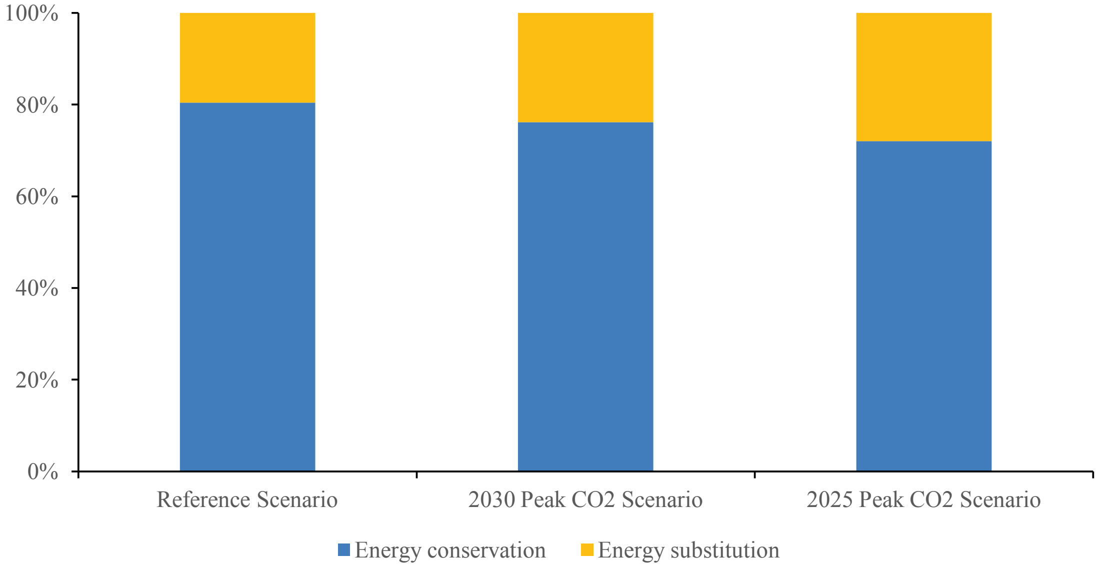
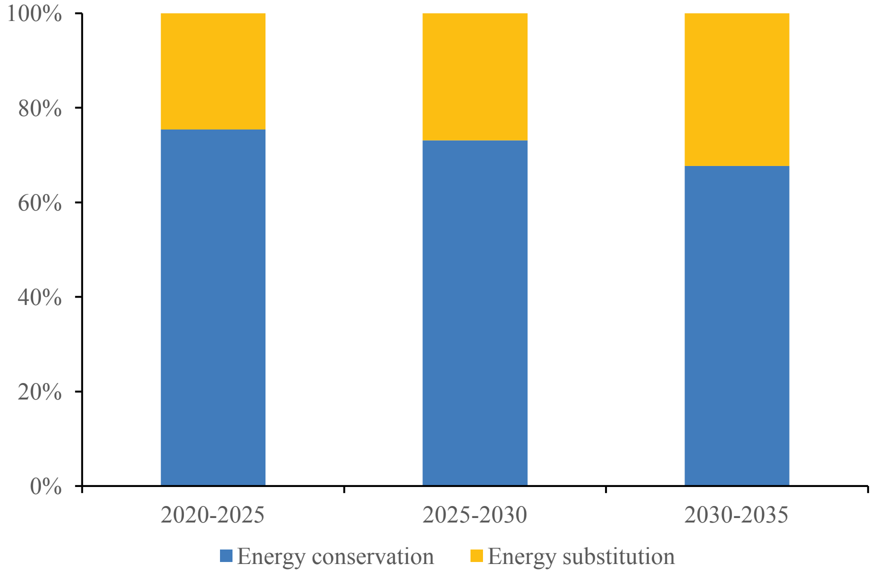


FIGURE 1- 10. The contribution of energy conservation and energy substitution to emissions reduction under the 2025 Peak CO_2 Scenario



REFERENCES

Asian Development Bank (ADB). (2015) Asian Development Outlook 2015 Update. Manila.

Armington, P. S. (1969). 'A theory of demand for products distinguished by place of production.' IMF Staff Papers 16: 159–176.

Arrow, K. J. and G. Debreu (1954). "Existence of an Equilibrium for a Competitive Economy." Econometrica 22(3): 265-290.

Böhringer, C., et al. (2003). Computable general equilibrium analysis: Opening a black box, ZEW, Zentrum für Europäische Wirtschaftsforschung.

Brooke, A., et al. (1992). GAMS: Release 2.25: a User's Guide, Scientific Press.

China National Bureau of Statistics. (2015). China Energy Statistical Yearbook 2014. China Statistics Press.

Energy Information Administration (EIA). (2014). International Energy Outlook 2014. Washington, DC.

EIU. (2015). Economic and Commodity Forecast. https://cn.knoema.com/loqqwx/china-gdp-growth-forecast-2015-2020-and-up-to-2060-data-and-charts

European Union (EU). (2015). China: Economic Outlook. Belgium.

International Energy Agency (IEA). (2016) World Energy Outlook 2016. Paris.

International Monetary Fund (IMF). (2012) World Economic outlook. Washington, DC.

International Monetary Fund (IMF). (2015). World Economic Outlook Update. Washington, DC.

Mathiesen, L. (1985). 'Computation of economic equilibria by a sequence of linear complementarity problems.' Mathematical Programming Study 23(OCT): 144-162.

Narayanan, B., et al. (2012). Global Trade, Assistance, and Production: The GTAP 8 Data Base, Center for Global Trade Analysis, Purdue University.

OECD. (2014). Economic Outlook No 95: long-term baseline projections. http://stats.oecd.org/Index.aspx?DataSetCode=EO95_LTB

OECD. (2015). Economic Outlook for Southeast Asia, China and India 2015. http://www.keepeek.com/Digital-Asset-Management/oecd/development/economic-outlook-for-southeast-asia-china-and-india-2015_saeo-2015-en#page24

OECD. (2016a). China-Economic forecast summary. http://www.oecd.org/economy/china-economic-forecast-summary.htm

OECD. (2016b). Global Economic Outlook. http://www.oecd.org/eco/outlook/economicoutlook.htm

Rutherford, T. F. (1999). 'Applied general equilibrium modeling with MPSGE as a GAMS subsystem: an overview of the modeling framework and syntax.' Computational Economics 14(1-2): 1-46.

Sue Wing, I. (2004). 'Computable general equilibrium models and their use in economy-wide policy analysis.' Technical Note, Joint Program on the Science and Policy of Global Change, MIT.

United Nations (UN). (2015a). World Economic Situation and Prospects 2015. New York.

United Nations (UN). (2015b). World Population Prospects, the 2015 Revision New York: Population Division, Department of Economic and Social Affairs.

World Bank (WB). (2015). Global Economic Prospects: The Global Economy in Transition. Washington, DC.

CHAPTER 2

GENERAL INTRODUCTION OF ENERGY EFFICIENCY DEVELOPMENT IN CHINA

Jingru Liu

2.1 GENERAL RESULT OF ENERGY CONSERVATION IN CHINA IN THE 12^{TH} FYP

The 12th Five-year Plan (2011-2015) for China's social and economic development sets an energy conservation target of 16% reduction in energy consumption per unit of GDP in 2015 on the level in 2010. According to the requirements of the Plan, energy use per unit of GDP had to reduce over 3.4% annually.

With the Chinese economy gradually entered the New Normal, economic growth has slowed down and adjustment of the economic structure has gradually progressed, with the growth rate of energy consumption gradually declining to 0.98% in 2015 from 7.32% in 2011. At same time, economic development dependent on energy consumption has continually declined as well. Therefore, during the period of the 12th Five-year Plan, energy use per unit of GDP declined by 2.0%, 3.7%, 3.8%, 4.8% and 5.5% in each year.

In total, energy use per unit of GDP declined 18.4% from 2010 to 2015, far exceeding the agreed target of 16% for the 12th FYP. The accumulative energy saving was 865 Mtce (see Table 2-1), equivalent to 1.82 Gt of CO_2 emission reductions.[1]

2.2 ENERGY EFFICIENCY IMPROVEMENTS IN KEY ENERGY END-USE SECTORS IN THE 12^{TH} FYP

In order to meet the agreed energy conservation target in the 12th Five-year Plan, the State Council has allocated the energy conservation target to the key energy-consuming sectors and industries. Besides energy conservation and emission mitigation in the 12th Five-year Plan, at the beginning of the Plan the Ministry of Industry and Information Technology issued an Industry Energy Conservation Plan, the Ministry of Housing and Urban-Rural Development published a Building Energy Conservation Plan, the Ministry of Transport issued a Highway Waterway Transportation Energy Conservation and Emissions Reduction Plan, the Ministry of Railways published a Railway Energy Conservation Plan, and the National Government Offices Administration issued an Energy Conservation Plan for Public Institutions. Energy-conservation indicators and targets were set out in these plans, basically constituting the anticipated indicators.

2.2.1 ENERGY EFFICIENCY IMPROVEMENTS IN INDUSTRIAL SECTORS

The Energy Conservation and Emission Mitigation Plan and Industrial Energy Conservation Plan in the 12th Five-year Plan have proposed targeted objectives, such as a 21% reduction in energy use of value-added in above-scale industries, a reduction rate of energy consumption per unit of industrial value-added in the major industries, and energy consumption per unit of key energy-intensive products.

By 2014, energy consumption per unit of value-added in above-scale industries declined by 21% compared with 2010, and the 12 FYP's target of energy conservation was achieved one year ahead of schedule (see Table 2-2).

According to statistics from relevant experts, energy consumption per unit of main products continually declined during the 12th FYP period, the gap between China and other countries having gradually been narrowed (see Table 2-3).

1 *The data are calculated by using the chaining method, that is, there is no single base year, but time series data are required, and for every year the previous year is used as the base.*

TABLE 2-1. Total energy consumption and energy intensity of China's GDP from 2010 to 2015

	GDP (IN 2010 CONSTANT PRICES)	TOTAL ENERGY USE(10^4TCE)	GDP GROWTH RATE	ENERGY USE GROWTH RATE	ENERGY USE ELASTICITY COEFFICIENT	ENERGY USE PER GDP (TCE/10^4 RMB)	REDUCTION RATE OF GDP ENERGY INTENSITY	ANNUAL ENERGY SAVING (10^4TCE)
2010	413,030	360,648	10.64%	7.30%	0.69	0.873	-	-
2011	452,419	387,043	9.54%	7.32%	0.77	0.855	2.0%	0.80
2012	487,962	402,138	7.86%	3.90%	0.50	0.824	3.7%	1.53
2013	525,816	416,913	7.76%	3.67%	0.47	0.793	3.8%	1.64
2014	564,189	425,806	7.30%	2.13%	0.29	0.755	4.8%	2.15
2015	603,198	430,000	6.91%	0.98%	0.14	0.713	5.5%	2.52

TABLE 2-2. Industrial Value-added and energy consumption in the 12th Five-year Plan Period

MAIN INDICATORS	2010	2014	TARGET IN 2015	PERFORMANCE IN THE FIRST FOUR YEARS OF THE 12TH FIVE-YEAR PLAN
Value-added of total industry (billion RMB, current price)	19,157.1	22,799.1	8%	8.31%
Energy intensity (energy consumption to value-added ratio) of above-scale industrial enterprises (in 2005 prices)	1.92	1.52	-21%	-21%

Source: China Statistics Yearbook 2016; Ministry of Industry and Information Technology

TABLE 2-3. Energy efficiency changes in key energy intensive products and production processes

	CHINA							INTERNATIONAL ADVANCED LEVEL
	2000	2005	2010	2011	2012	2013	2014	
Coal mining, washing and screening								
Gross energy use (kgce/t)	38.2	32	32.7	32.5	31.8	30.2		
Power use (kWh/t)	29	25.1	24.0	24.0	23.4	25.8	24.3	17.0
Oil and natural gas exploitation								
Gross energy use (kgce/toe)	208	163	141	132	126	121	125	105
Power use (kWh/toe)	172	171	121	127	121	123	132	90
Co-fired thermal power generation (gce/kWh)	363	343	312	308	305	302	300	292
Coal-fired power supply (gce/kWh)	392	370	333	329	325	321	319	302
Steel production (kgce/t)								
-Whole industry	1475	1020	950	942	940	923	913	
-Large and medium enterprises	906	760	701	695	694	682	674	
-Steel comparable energy use	784	732	681	675	674	662	654	610
AC Power use of Electrolytic aluminium manufacturing (kWh/t)	15418	14575	13979	13913	13844	13740	13596	12900
Copper smelting (kgce/t)	1227	780	500	497	451	436	420	360
Cement production (kgce/t)	172	149	134	129	127	125	124	18
Wall material manufacturing (kgce/10^4 standard bricks)	763	478	468	454	449	449	454	300
Comprehensive energy use of architectural ceramics (kgce/m^2)	8.6	8.0	7.7	7.4	7.3	7.1	7.0	3.4
Flat glass manufacturing (kgce/50kg)	25.0	22.7	16.9	16.5	16.0	15.0	7.1	13.0
Oil processing (kgce/t)	118	114	100	97	93	94	97	73
Ethylene production (kgce/t)	1125	1073	950	895	893	879	860	629
Synthetic ammonia production (kgce/t)	1699	1700	1587	1568	1552	1532	1540	990
Comprehensive energy use of caustic soda/kgce/t	1439	1297	1006	1060	986	972	949	910
Soda ash production (kgce/t)	406	396	385	384	376	337	336	310
Power use for calcium carbide production (kWh/t)	3475	3450	3340	3450	3360	3423	3272	3000
Paper and paper board manufacturing								
-Whole industry(kgce/t)	912	528	390	380	366	353	340	
- Enterprises using own made paper pulp (kgce/t)	1540	1380	1200	1170	1128	1087	1050	580
-Power use of chemical fiber (kWh/t)	2276	1396	967	951	878	849	801	800

Sources: Wang Qingyi, China Energy Data (2015), China Energy Data (2014)

TABLE 2-4. Building energy conservation targets set in the Energy Conservation and Emission Mitigation Plan for the 12 FYP period

ITEMS	UNIT	2010	2015	CHANGE
Floor areas of energy conservation retrofits for existing residential buildings in northern China	$10^8 m^2$	1.8	5.8	4
Percentage of green building standard enforcement among new buildings (both urban and rural)	%	1	15	14
Residential building energy conservation retrofits in the zones of hot summer and cold winter	$10^8 m^2$			0.5
Energy conservation retrofits for public buildings	$10^8 m^2$			0.6

2.2.2 ENERGY EFFICIENCY IMPROVEMENTS IN THE BUILDING SECTOR

The Energy Conservation and Emission Mitigation Plan and the Building Energy Conservation Plan for the Building Sector in the 12th Five-year Plan have set out energy conservation targeted indicators, such as the floor areas of energy conservation retrofits for existing residential buildings in northern China and green building development. The energy conservation targets set out in the Energy Conservation and Emission Mitigation Plan for the 12th Five-year Plan are shown in Table 2-4.

According to statistical data from the MOHURD, information about achieving energy conservation targets is as follows:

1. Energy conservation standards enforcement among new buildings. By the end of 2015, the enforcement rate of compulsory energy-conservation standards basically reached 100% in all urban areas. Beijing, Tianjin, Shandong Province, Tangshan City in Hebei Province, Urumqi of Xinjiang etc. have already enforced local energy-conservation standards among 75% of the new buildings. By the end of 2014, the area of accumulated constructed energy-conservation buildings was 11.35 billion m^2 in the whole country.[2]
2. Energy conservation retrofits for existing residential buildings. In the first four years of the 12th Five-year Plan, the area of heating supply metering and energy conservation retrofits for existing residential buildings is 830 million m^2 in urban northern China, where space heating provision is a mandatory responsibility for the government, exceeding the target of 400 million m^2 set by the State Council. In 2015, the target was 160 million m^2, and 167 million m^2 of retrofit had been achieved. The total area of energy conservation retrofit floors is expected to be 1 billion m^2 during the 12th Five-year period. By the end of 2014, floor areas with heating metering charges had reached 1.1 billion m^2. In the 12th Five-year Plan, energy conservation pilots were conducted on 7090 m^2 of existing residential buildings in the hot summer and cold winter areas, exceeding the target set by the State Council.[3]
3. Energy conservation retrofits of public buildings. By the end of 2014, the energy audit for public buildings had covered over 12,900 buildings nationwide, and energy consumption of more than 13,000 buildings had been audited and published. A dynamic monitoring platform for the energy use of public buildings had been created in 33 provinces (autonomous regions and metropolitans), and the energy consumption of over 7400 buildings was being monitored. By the end of 2014, energy conservation retrofits for public buildings had reached 39.28 million square meters countrywide, and 32.64 million square meters was scheduled to complete in 2015. An energy-conservation supervision system construction pilot has been conducted in 256 colleges and universities, 44 hospitals and 19 scientific research institutes.
4. Green building development. By the end of October 2015, 3600 programs had passed assessment and obtained green building labels in the whole country, and the total floor area had reached 420 million square meters. Beijing, Chongqing, Jiangsu, Zhejiang and Shenzhen etc., have started to enforce green building standards compulsorily in newly constructed buildings in cities and towns, and nearly 400 million square meters of green building had been compulsorily introduced. Affordable housing projects in the above capital cities of provinces have started to enforce green building standards compulsorily. It was predicted that the floor areas of newly constructed green buildings will total over 1 billion square meters across the country by the end of 2015, thus successfully achieving the target set out in the 12th FYP.
5. Renewable energy applications in buildings. By the end of 2014, areas of solar-thermal application in national cities and towns had reached 2.7 billion m^2, areas of shallow geothermal energy application 460 million m^2, and installed capacity of building integrated solar PV 2500 MW. 25 renewable energy applications in building promotion had been promoted at the provincial level, together with 93 pilot

2 *Source: the Ministry of Housing and Urban-Rural Development.*

3 *Source: the Ministry of Housing and Urban-Rural Development.*

TABLE 2-5. Energy conservation targets set in the Energy Conservation and Emission Mitigation Plan for the Transport Sector for the 12th FYP period

INDICATORS	2010	2015	CHANGE RANGE/ RATE
Gross energy efficiency of railway transport (tce/million ton·km)	5.01	4.76	[-5%]
Energy use of vehicles in operation unit transport turnover (kgce/100 ton·km)	7.9	7.5	[-5%]
Energy use of ships in operation unit transport turnover (kgce/1000 km)	6.99	6.29	[-10%]
Energy use of civil aviation transport turnover (kgce/ton·km)	0.45	0.428	[-5%]

Source: Chinese Ministry of Transport

cities of renewable energy integrated in buildings, 98 demonstration counties, 608 solar PV integrated in building pilot projects and 8 solar energy comprehensive utilization pilots at the provincial level.

2.2.3 ENERGY EFFICIENCY IMPROVEMENTS IN THE TRANSPORTATION SECTOR

The energy-conservation targets set out in the Energy Conservation and Emission Mitigation Plan for the transportation sector in the 12th Five-year period is shown in Table 2-5.

In respect of energy conservation in relation to highways and waterway transport, the Ministry of Transport issued *a Highway and Waterway Transportation Energy Conservation and Emissions Reduction Plan in the 12th FYP*, which proposes an energy efficiency target: compared to the level in 2005, gross energy use efficiency of vehicles in operation for each transport turnover shall reduce 10% by 2010, and that of passenger vehicles in operation and freight vehicles in operation will decline 6% and 12% respectively; energy efficiency of waterway transport shall decline 15%, with that of marine transport and inland waterway transport decline 16% and 14% respectively; and the gross energy efficiency of port operation shall reduce 8%.

In 2013, the Ministry of Transport organized a mid-term assessment for transport energy conservation in the 12th FYP. The results show that highway and waterway transport had already completed their energy conservation targets set out in the 12th FYP within three years. As shown in Table 2-6, most targets had been reached ahead of schedule.

As for railway transport, statistical data published by the National Railway Corporation indicated that, compared to 2010, gross energy efficiency of the national railways and the major railway transport businesses in 2014 had declined 10% and 7.3% respectively, far exceeding the target of 5% reduction in five years. In the civil aviation sector, it was predicted that the average oil use per person km would decline 4.2% in the 12th FYP period.

2.2.4 ENERGY CONSERVATION INDICATORS OF PUBLIC INSTITUTES

The Energy Conservation and Emission Mitigation Plan for the 12th FYP Period and the *12th Five-year Energy Conservation Plan for the Public Institutes* have set out energy conservation targets for public institutes: energy use per square meter of building floor in 2015 shall be 12% compared with the level in 2010, and per capita energy use shall decline 15%.

TABLE 2-6. Progresses in realizing the road and waterway transportation energy conservation targets in the 12th Five-year Period

Indicators	2010-2015 Target (improvement from base year 2005)	Reduction in 2013 Compared with 2005 level	Accomplishment
Road transport energy efficiency	10%	11.70%	117%
Energy·efficiency of road passenger transport (per person·km)	6%	12.40%	207%
Energy efficiency of road freight transport (per ton·km)	12%	11.80%	98%
Energy efficiency of waterway transport (per ton·km)	15%	16.30%	109%
Energy efficiency of marine transport (per ton·km)	16%	14.40%	90%
Energy efficiency of inland waterway transport (per ton·km)	14%	19.50%	139%
Energy efficiency of port operation (per ton of handling capacity)	8%	14.30%	179%

Source: Chinese Ministry of Transport

TABLE 2-7. Energy conservation performances of public institutes

ITEMS	2010	2014	ENERGY EFFICIENCY TARGET (2011-2015)	ACCUMULATED REDUCTION IN 2014
Energy use per m^2 of building floor areas ($kgce/m^2$)	23.9	21.78	12%	11.05%
Per capita energy use (kgce/person)	447.4	385.11	15%	13.92%

In 2014, the floor area based energy intensity of public institutes was 21.78 $kgce/m^2$, and per capita energy use was 385.11 kgce/person, declining 11.05% and 13.92% respectively from the levels in 2010. Progress in achieving the energy conservation target was 91.6% and 92.2% respectively, both exceeding 80% of the established targets[4] (see Table 2-7).

2.2.5. ACHIEVEMENT OF ENERGY CONSERVATION INVESTMENT IN THE 11TH AND 12TH FYPS

In the period of the 11th FYP, the Chinese Government stated that energy use per 10,000 RMB of GDP (on fixed price basis) should be 20% less in 2010 than the level in 2005. The GDP energy intensity actually declined 19.1% from the 2005 level during 2006-2010, in other words the country almost realized its energy conservation target in the 11th FYP. During the five years, the government invested 846.6 billion RMB in energy efficiency improvement. The public funds were used to support technical projects and relevant capacity-building, directly generating 339.9 Mtce of energy savings and contributed 53.8% to the 19.1% energy-use reduction achieved.

In the first four years of the 12th FYP, the total investment in energy conservation in China reached RMB 1547.53 billion, resulting in a total energy saving of 284.3 Mtce. This directly contributed 47.1% to the 13.4% of GDP energy intensity reduction achieved during the first four years of the 12th FYP period.

2.3 OUTLOOK ON ENERGY CONSERVATION OPPORTUNITIES IN THE 13TH FYP

In the Outlines of the 13th National FYP (2016-2020) for Economic and Social Development, a new 15% target has been set to further reduce the country's GDP energy intensity.

4 *Source: National Government Offices Administration.*

During the 13th FYP period, the role of economic structure optimization in boosting energy conservation is prioritized, but technology is also expected to play an important role in energy conservation. It is estimated that to achieve the target, the total energy conservation investment need will reach RMB 1.68 trillion and lead to 225 Mtce of energy saving.

Although great improvements have been made in China in energy efficiency in recent years, there is still much energy-conservation potential and many opportunities in the country.

It is estimated that the realizable energy-conservation potential will be 802.28 Mtce, exceeding the requirements of the 716.04 Mtce of energy-conservation target for the 13th FYP. All these energy-conservation opportunities are scattered across different energy end-use sectors, including industry, buildings and transportation.

2.4 METHODOLOGY

The study's vision is that, by pursuing high impact opportunities for energy efficiency, China can meet the energy demand of its economic growth with a clean, efficient, low-carbon, safe and modern energy system. To generate some meaningful insights into China's energy consumption, this study combines top-down analysis and bottom-up analysis to research long-term energy development and energy efficiency potentials systematically and quantitatively. The top-down analysis is based on GDP size and growth rate, population and urbanization, and the experiences and lessons of advanced countries, taking into account China's specific conditions, development stages and levels. The bottom-up analysis focuses on the energy end-use sectors of Chinese economy: industry, buildings, transport and energy transformation (including both electricity and other energy-supply sectors). The analysis includes assessments of sectoral energy demand and activity levels, structural change and technical improvements.

The Long-Range Energy Alternatives Planning (LEAP) system is used to assess future energy-demand pathways and energy-efficiency potentials. The LEAP model, developed by the Stockholm Environment Institute, is an

integrated modeling tool that can be used to track energy consumption, production and resource extraction in all sectors of an economy and follows an end-use and demand-driven approach. In this study, given the state of China's current statistical system, the LEAP model covers industry and the buildings, transport, and power sectors, as well as agriculture, construction, mining, oil-refining, coking, coal to oil/gas and some other sectors. The industry sector has 21 subsectors and distinguishes energy-intensive sectors from other manufacturing sectors. The buildings sector is divided by climate zones and has residential, commercial and public building subsectors. The transportation sector analyzes the demands for freight and passenger transport, distinguishing the following transport modes: rail, road, shipping, aviation and pipelines. The transformation sector covers electricity, combined heat and power generation, and heat-supply modules.

Two distinct scenarios are developed in preparing the storylines from 2010 to 2050. The Reference Scenario considers current policies for energy efficiency, excludes new ambitious policies, and envisions little or mild technical improvements. Under the Intensified Energy-saving Scenario, China is expected to meet its energy needs and improve its environmental quality by tapping cost-effective energy-efficiency improvement potentials and increasing renewable energy supply in the years to 2050. Given the fact that China is undergoing fast industrialization and urbanization, high impact opportunities of energy efficiency - not only from technical improvements and breakthrough, but also from economic structural change and consumer behavior change - are both covered and analyzed. For both scenarios, the same macroeconomic drivers and assumptions were adopted based on existing Chinese and international projections, as shown in Table 2-8.

TABLE 2-8. Macroeconomic drivers and assumptions for both scenarios

	2010	2020	2030	2040	2050
Total Population (billions)	1.34	1.42	1.44	1.42	1.37
Urbanization Rate (% of population)	50%	60%	68%	74%	78%
Decadal Annual Average GDP Growth Rate (%)	7.6%	5.9%	4.1%	2.9%	

3 CHAPTER

ENERGY EFFICIENCY POLICY AND HIGH IMPACT OPPORTUNITIES FOR THE INDUSTRIAL SECTOR

Guanyun FU
Huawen XIONG

3.1 THE CHARACTERISTICS OF ENERGY CONSUMPTION IN THE INDUSTRIAL SECTOR AND PROGRESS WITH ENERGY EFFICIENCY

For a long time, the industrial sector has been the largest contributor to national economic development, with more than 40% of economic outputs coming from industry. However, due to low levels of energy efficiency and poor treatment of pollutants, energy consumption in the industrial sector has grown in parallel with the expansion of economic outputs. The proportion of primary energy consumption has remained high at a level of 70%, more or less, while emissions of environmental pollutants such as sulfur dioxide, nitrogen oxides and smoke dust, as well as carbon dioxide, account for up to 70% above among national emissions. Smooth progress with energy efficiency in the industrial sector is of great strategic significance to the solution of such problems, like the constraints on energy, the ecological restraints and the environmental constraints.

3.1.1 INDUSTRY DOMINATES ENERGY CONSUMPTION IN CHINA

Industry is the largest energy-consuming sector in China, consistently accounting for about two thirds of the national total energy consumed. Since 2000, with sustained and rapid economic development, accelerated industrialization and urbanization and annual GDP growth rates of nearly 10%, total consumed energy has correspondingly shown steady growth from 1.47 gigatonnes of coal equivalent (Gtce) in 2000 to 4.3 Gtce in 2015, with average annual growth rates of up to 7.5%. During the corresponding period, the annual average growth rates of industrial value added (VA) and of industrial energy consumption respectively recorded 10.5% and 8.1%. As shown in Figure 3-1, in 2014 energy consumption in China's industrial sector reached 2.83 Gtce, accounting for 66.6% of national total energy consumption, and representing an increase of 0.2% over 2001.

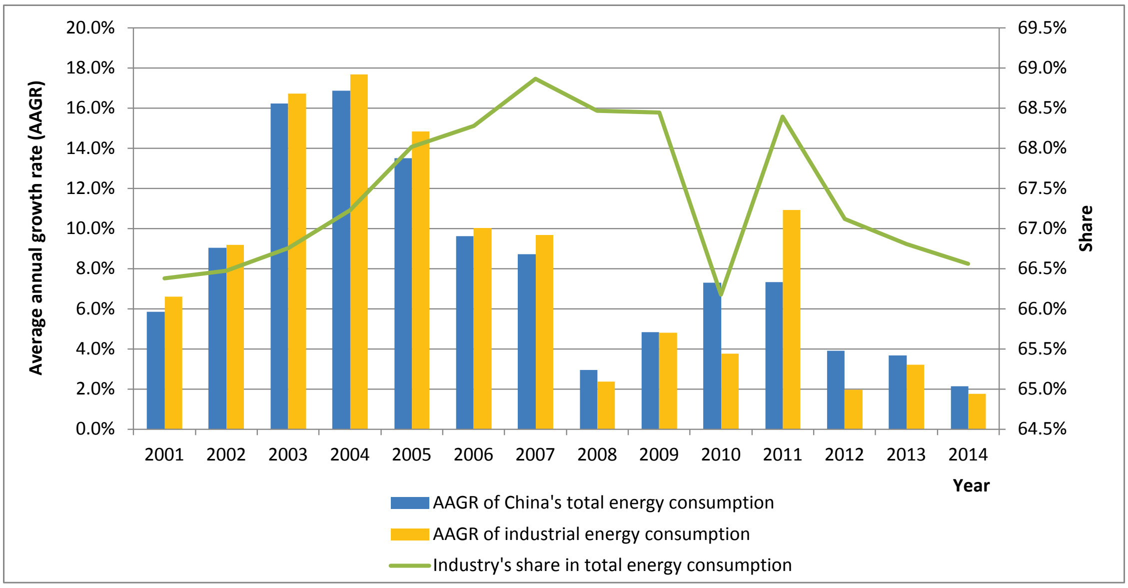
3.1.2 ENERGY-INTENSIVE INDUSTRY IS A KEY FIELD FOR INDUSTRIAL ENERGY CONSUMPTION IN RECENT YEARS

Energy-intensive industries[5] constitute the majority of industrial energy consumption. Since 2000, China's six major energy-intensive industries have recorded an annual energy consumption growth rate of 10%, 1.4 percentage points higher than the all industrial sectors' annual energy consumption growth rate of 8.6%. In 2003 and 2004, the annual energy consumption growth rates of energy-intensive industries even exceeded 20%. In 2008, under the impact of the global financial crisis, the energy consumption growth rate of energy-intensive industries

5 *The six energy intensive industries mentioned in this Chapter include building materials, steel, non-ferrous metals, paper-making, chemical engineering and petrochemicals.*

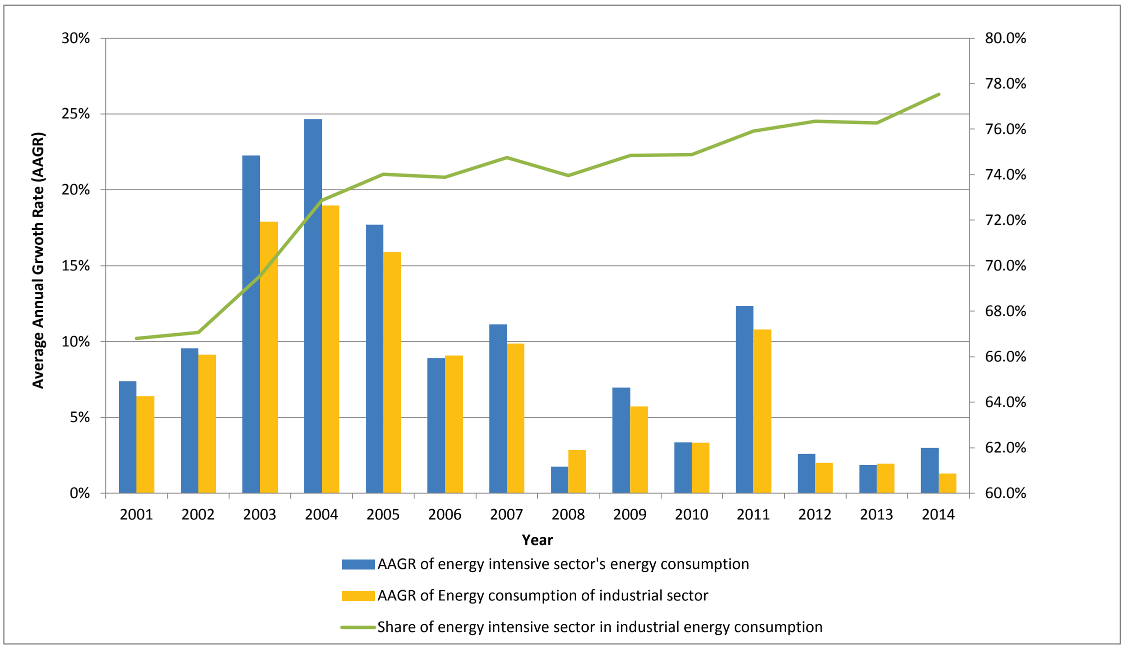
FIGURE 3-1. Total energy consumption and the growth of industrial energy consumption during 2001-2014

Note: The amount of energy consumption is calculated using the coal equivalent calculation method



Data source: China Energy Statistical Yearbook 2015

FIGURE 3-2. Energy consumption growth in high-energy-consuming industries during 2001-2014



Data Source: State Statistics Bureau, National Energy Administration, China Energy Statistical Yearbook 2015

declined sharply from 11.1% in 2007 to 1.8% in 2008. During 2008 - 2014, except for 2009 and 2011, energy-intensive industries' annual energy consumption growth rates were 3% or even lower. Since 2003, the proportion of energy-intensive industries in the energy consumption of all industrial sectors has remained 70% or above (as shown in Figure 3-2); during 2003 - 2013, this proportion rose steadily and reached 77.5% in 2014.

In terms of energy-consumption development trends in major energy-intensive industries, during the period from 2000 to 2013, the highest energy consumption growth rates appeared in steel, non-ferrous metals, chemicals and building materials industries; in 2013, energy consumption in these four industrial sectors were respectively 4.0, 3.8, 3.3 and 3.3 times the levels in 2000. The petrochemical and pulp and paper industries recorded relatively slow increases in energy consumption, with their energy consumption only doubled during the period. On the other hand, during 2000-2013, energy consumption in iron and steel, non-ferrous metals and the chemical and petroleum chemical industries maintained steady growth, while energy consumption in the building materials and pulp and paper industries peaked in 2011 and 2009 respectively and have been falling since then (see Figure 3-3).

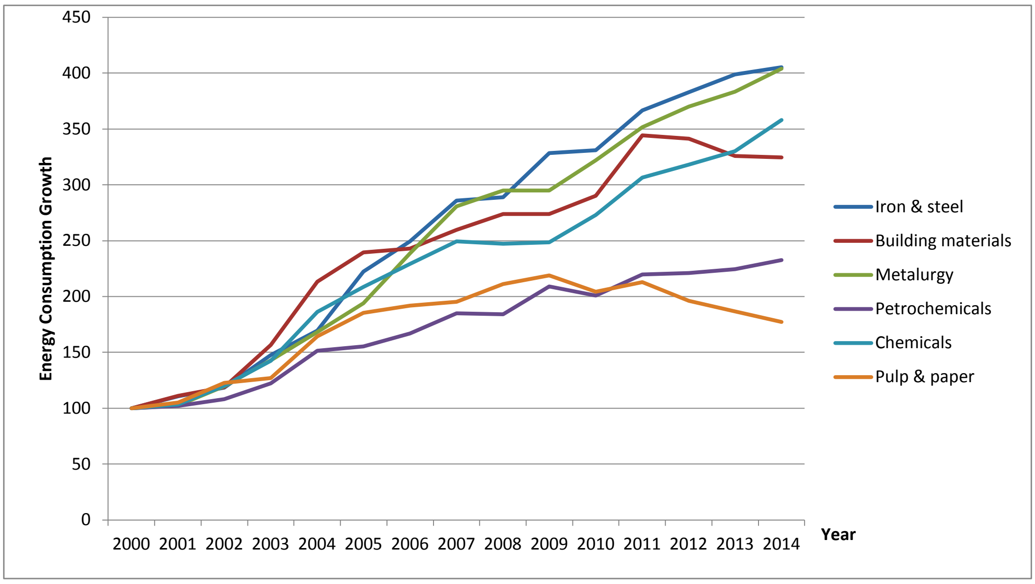
3.1.3 THE DOMINANT ROLE OF COAL IN THE FINAL ENERGY CONSUMPTION OF INDUSTRY

In China's industrial final energy-consumption, a large proportion is coal and coke and the share of natural gas is much smaller. In 2014, coal and coke accounted for as much as 52.7% of the final energy consumption by industry, while natural gas only accounted for 5.1% (see Figure 3-4). Comparison shows that China's industrial final energy consumption structure is almost the opposite to that of developed countries. In developed countries, generally less than 10% of the industrial final energy consumption is coal and coke. For example, the shares are only 4% in the US and less than 10% in the UK, Japan and Germany, while in China it exceeds 50%. In terms of the share of natural gas in final energy consumption by industry, this value exceeds 50% in most developed countries and it is just 5% in China. China's industrial final energy consumption structure is 'dominated by coal' and therefore the carbon intensity of industrial energy consumption is high.

3.1.4 THE EFFICIENCY OF ENERGY UTILIZATION IS SIGNIFICANTLY IMPROVED

In the past ten years, in order to improve the energy efficiency of the industrial sector, the Chinese government has launched an energy-efficiency program for key enterprises in energy-intensive industries, including steel, non-ferrous metals, coal, petroleum and petrochemicals, chemicals and building materials, thus speeding up the

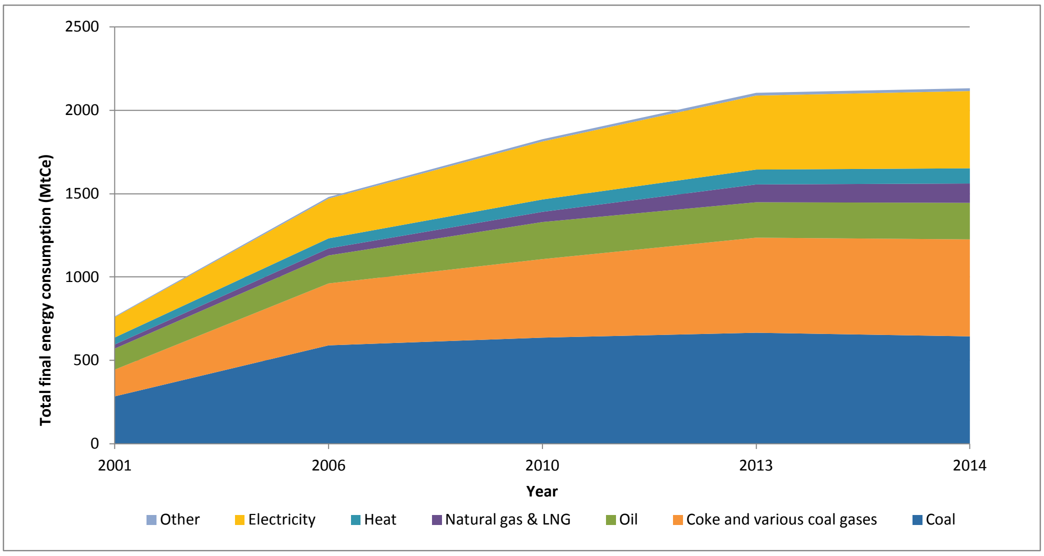
FIGURE 3-3. Variations in energy consumption indexes for China's major energy-intensive industries during 2000-2014



Data source: China Energy Statistical Yearbook 2015
Note: energy consumption in 2000 is defined as 100

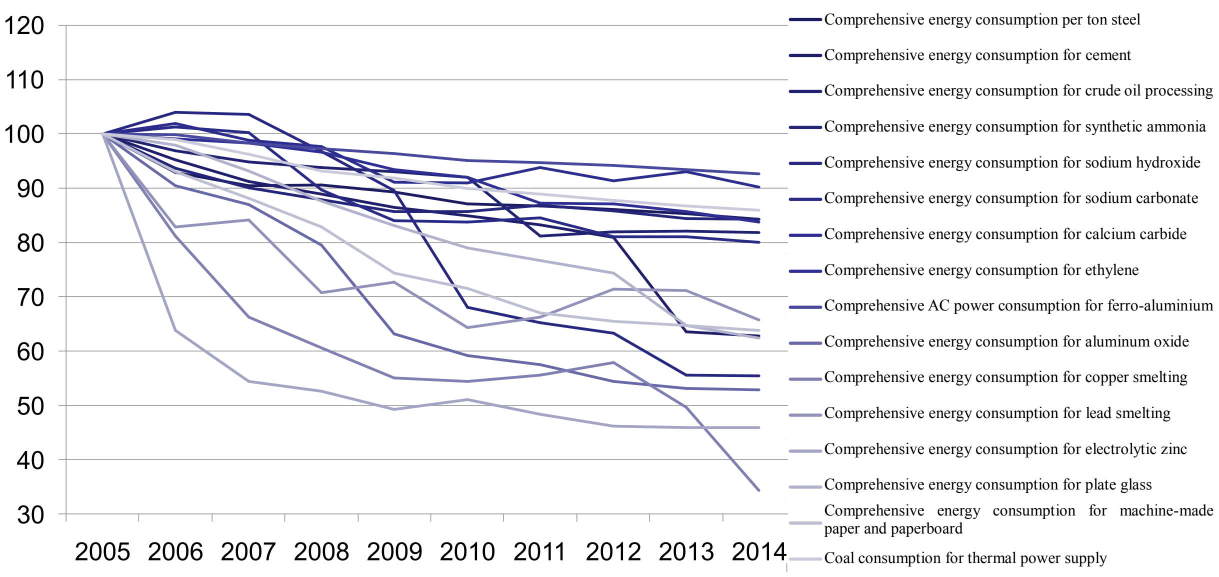
application of new energy-efficiency technologies, new processes and the manufacturing of new products, and eliminating outmoded industrial production capacities. Under the joint efforts of both government and enterprises, energy efficiency has improved significantly. As shown in Figure 3-5, during the period from 2005 to 2014, the energy efficiency of major energy-intensive products was improved by 15% to 25%. During the 11th FYP in particular the energy efficiency of energy-intensive product manufacturing, such as cement, plate glass and crude steel was significantly improved. At present, some Chinese enterprises such as Baosteel and Anhui Conch Cement have topped the global rankings in terms of energy efficiency. As shown in Figure 3-6, in China the overall energy efficiency in the manufacturing of energy-intensive products such as steel, cement and caustic soda only fall behind the most advanced international level by 10%, while the energy efficiency of coal-based power generation and aluminum production has even reached leading international levels.

FIGURE 3-4. Changes in the industrial energy structure



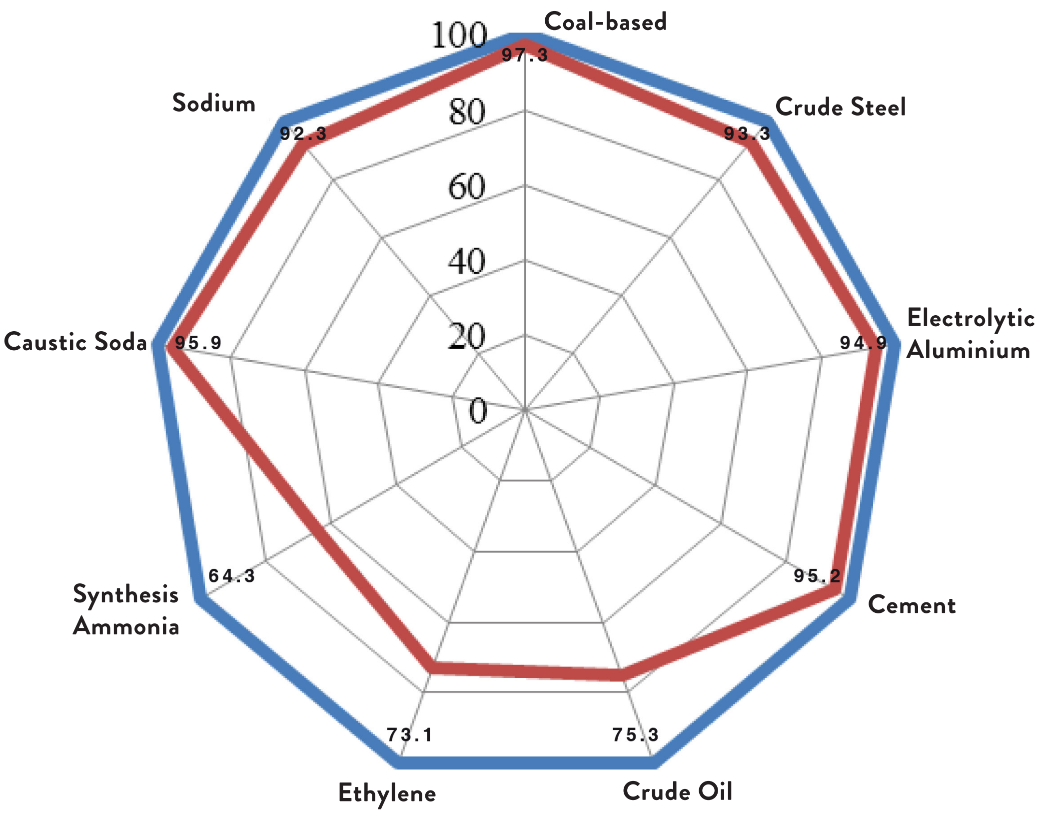
Data source: China Energy Statistical Yearbook 2015

FIGURE 3-5. Improvements in the unit consumption of major energy-intensive products



Data source: Various industry associations; Wang Qingyi, 'Energy data 2015'

FIGURE 3-6. Comparison between the unit consumption rates of major energy-intensive products and the advanced international level in 2014



Data source: Wang Qingyi, 'Energy data 2015'

3.2 OUTLOOK OF ENERGY CONSUMPTION IN INDUSTRIAL SECTORS

To analyze trends in energy consumption in industrial sectors in the future, this research adopts a 'bottom up' model, first analyzes and makes assumptions about the major driving factors that influence energy consumption, then forecasts the total energy consumption and energy mix in the industrial sector, as well as the energy consumption in each subsector.

3.2.1 METHODOLOGY

The key objectives in promoting energy efficiency in industrial sectors are to optimize the industrial structure and the internal structure of each industrial subsector, improve industrial production technologies and technology levels, and encourage a low-carbon and cleaner structure of industrial energy consumption. Essentially, interventions are made at three levels: economic activity, production technology, and energy mix. For this reason, the top-down macroeconomic model and the bottom-up LEAP model are used to project the future industrial energy-consumption under different scenarios.

Overall structure of the LEAP model for predicting energy consumption in the industrial sector is shown Figure 3-7. The industrial sector is divided into different subsectors, and the the activity levels and energy intensities are then assumed for each subsector. For each energy-intensive industrial subsector, the product yield (the yields of products such as crude steel, cement and electrolytic aluminum) is used as main indicator for the activity level and the rate of physical energy efficiency (energy consumption the production of a ton of steel and a ton of cement) is used as indicator representing the energy-intensity level. For each non-energy-intensive subsector, the energy consumption is predicted based on industrial value added as indicator for the activity level and the energy intensity per value-added as the indicator for the energy-intensity level.

3.2.2 KEY ASSUMPTIONS

The key parameters which influence the energy consumption of the industrial sectors include the industrial structure, the yields of major energy-intensive products and energy efficiency levels.

The industrial structure and the internal structure each industrial subsector

China has entered the mid-to-late stage in the process of industrialization. According to the historical experiences of developed countries, the industrial share of GDP will generally remain stable with slight declines. During the 13th FYP and in the coming decades, this will also be the case in China. Given the mutual integration of industrialization and digitalization, and the integration of manufacturing industry and the service sector, as well as the great development opportunities provided by the internet economy in such fields as finance and technical Research and Development, the research group made estimates about the share of industrial added value in GDP

FIGURE 3-7. **The basic structure of the energy consumption analysis model for various industrial sectors**

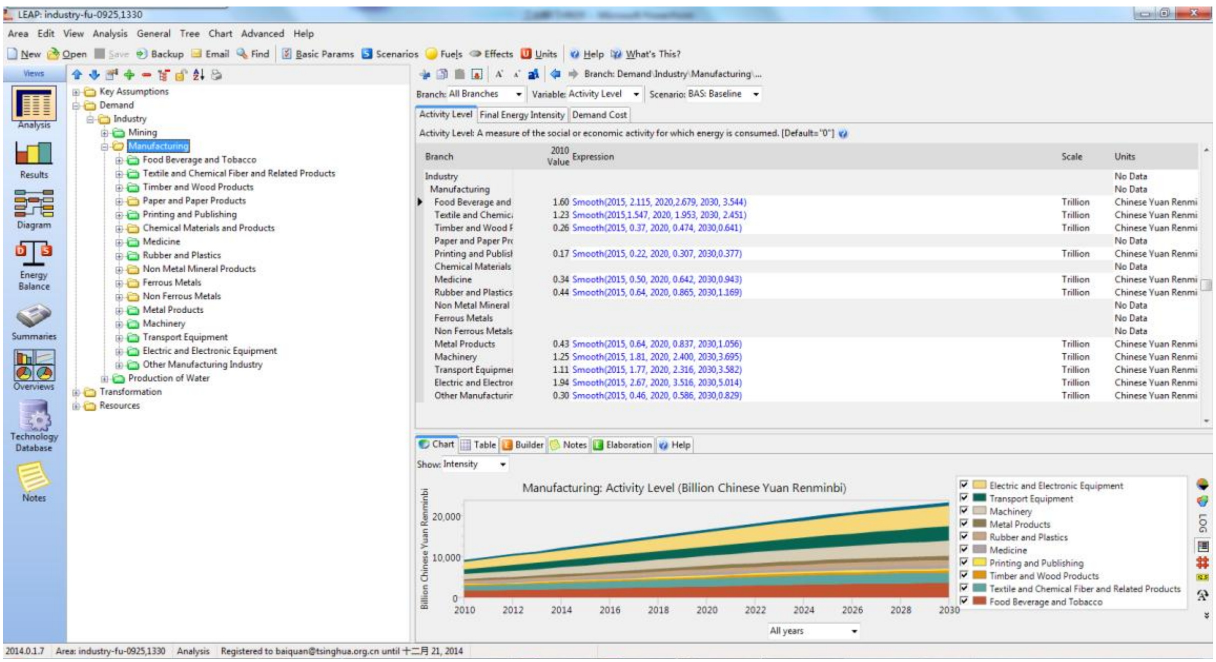
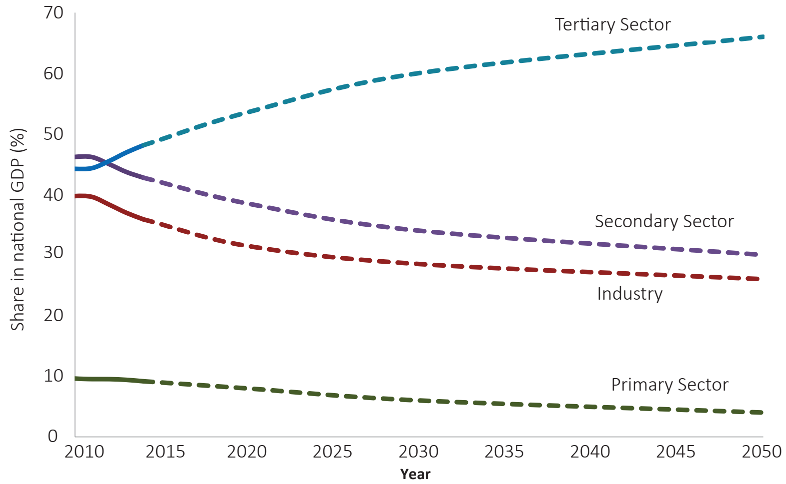


FIGURE 3-8. The changing trend in China's economic structure in the future (%)



Note: the primary sector includes agriculture, fishery, husbandry, forestry; the secondary sector includes industry and construction; the tertiary sector is the service sector

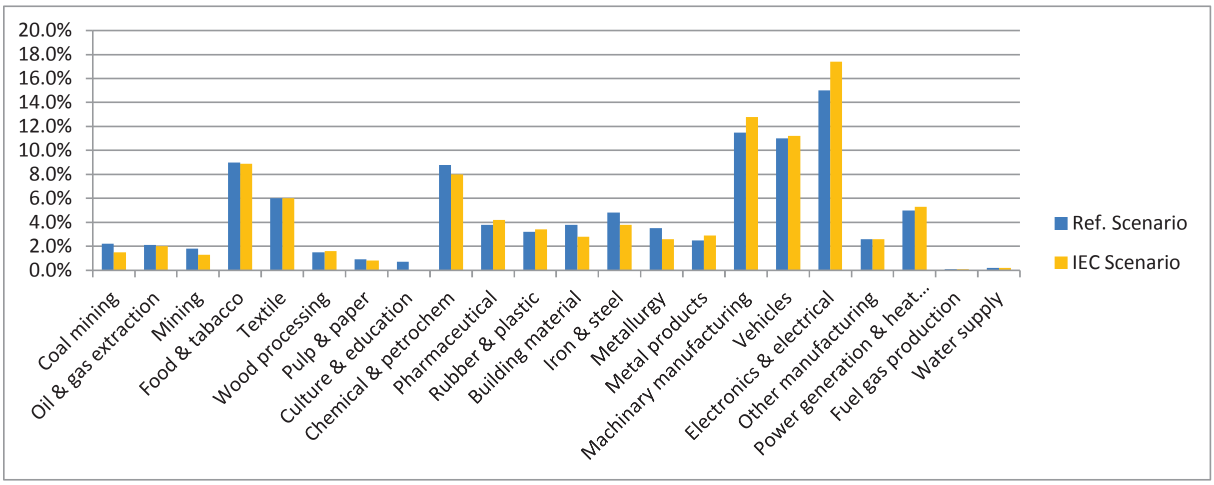
as shown in Figure 3-8. In 2050, the shares of secondary industry and the industrial value-added in China's GDP will fall to 30% and 26% respectively.

Within the industrial sector, traditional industries and emerging industries will have different developmental trends under the Reference Scenario and the Enhanced Energy Efficiency Scenarios. Some resource-intensive industries such as mining, steel and cement will shrink under the pressure of rising costs and decreasing market sizes, and there will be a significant decrease in the GDP proportion of their industrial added values. Some labor-intensive industries, such as food-manufacturing, printing and dyeing, and textiles, will pursue technology and product upgradation, thus increasing their industrial value-added; however, due to limited market capacity, ultimately there will be a slight drop in the GDP proportion of value-added in these industries. Based on data from Japan, Germany, Korea and the US, it is projected that those high value-added industries, including machinery, transport and communication facilities, electrical equipment and the chemical product manufacturing industry, will account for half of value-added of the whole industrial sector. Therefore, the GDP proportion of these industries will show significant increases. The structure of the industrial sectors in terms of value-added shares is shown in Figure 3-9.

Key energy-intensive products

Having experienced a 'golden decade' of development from 2000 to 2010, China's energy-intensive industries showed obvious declines in expansion rate during the 12th FYP period. At present, most energy-intensive industries are struggling with excessive production capacity in China, with relatively low enterprise benefit margins and

FIGURE 3-9. The industrial sector's internal structure under different scenarios in 2050 based the their shares in the added-value of the industrial sector

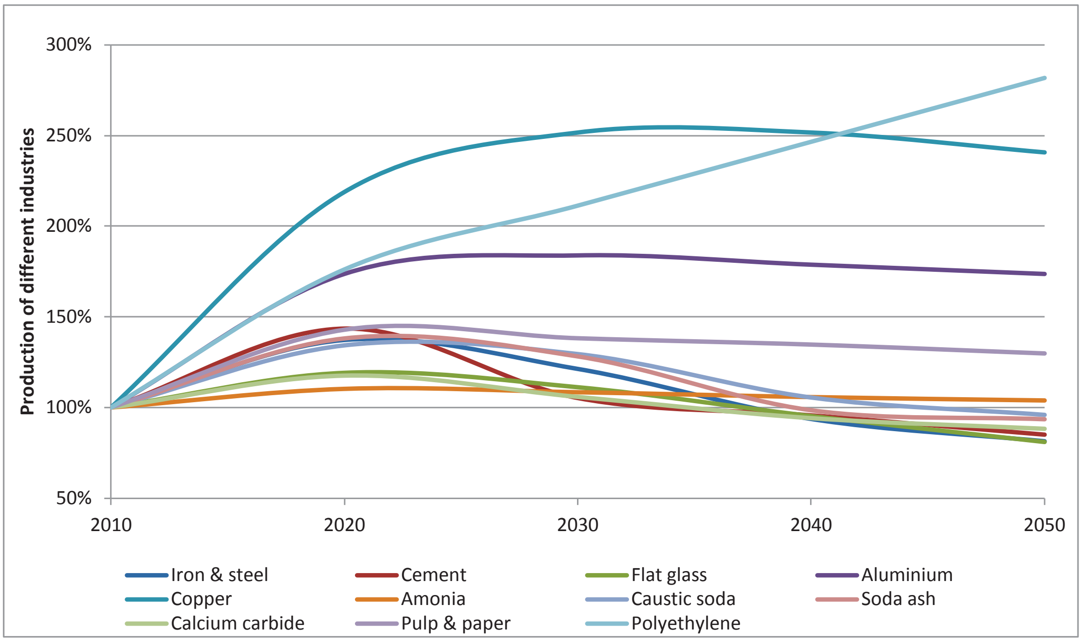


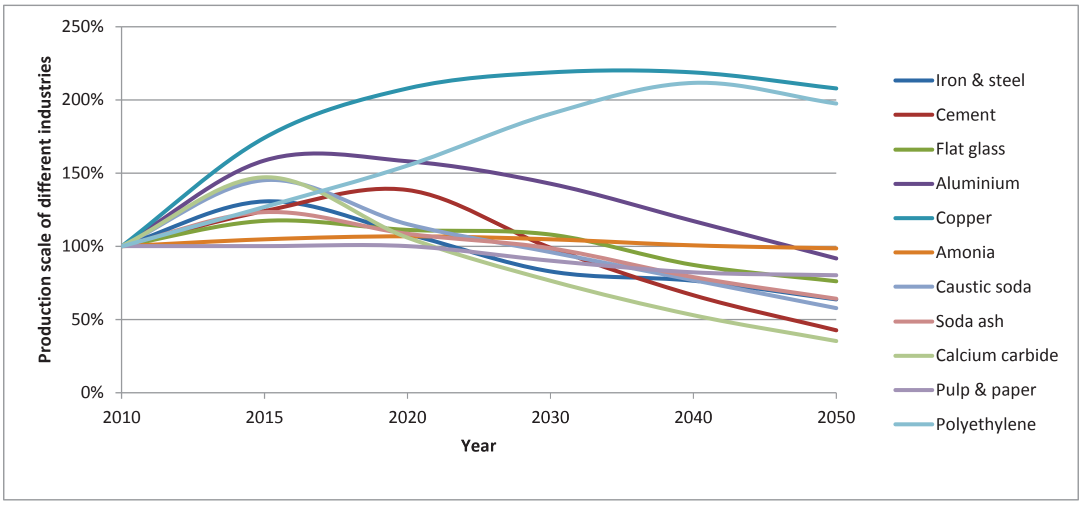
profit levels. During the 13th FYP period, although China is still at the mid-to-late stages of industrialization and the whole society's demand for energy-intensive products represented by basic raw materials will remain stable, then the demand is expected decline, and the yields of energy-intensive products such as steel, cement and plate glass will see a peak in their market demand. A dramatic decline in the total demand for energy-intensive products is predicted to appear after 2020 (see Figure 3-10). By 2025, per capita consumption of energy-intensive products such as steel and cement will reach the present average level of developed countries.

Energy efficiency

Energy efficiency is closely related to production processes, raw materials, equipment and technologies. Through comparing the Chinese industrial sector with the international predicted the energy efficiency level changes in the manufacturing of key energy-intensive products during 2010 - 2050 by taking into account the production processes for different energy-intensive products, as well as the potential for improving the energy efficiency to these processes. The results of the predictions are shown in Figure 3-11. The cement and paper industries possess energy-efficiency improvement potentials of 20%

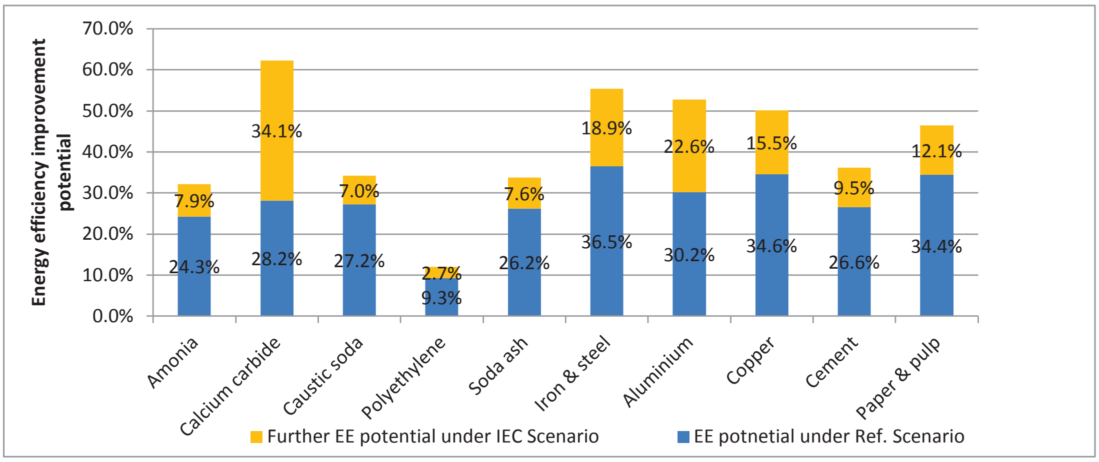
FIGURE 3-10. Variation trend of the yields of major energy-intensive products under different scenarios





Note: The Reference Scenario is shown in the upper figure, the Intensified Energy Conservation Scenario in the lower figure

FIGURE 3-11. The energy efficiency improvement potentials of energy-intensive industries under different scenarios



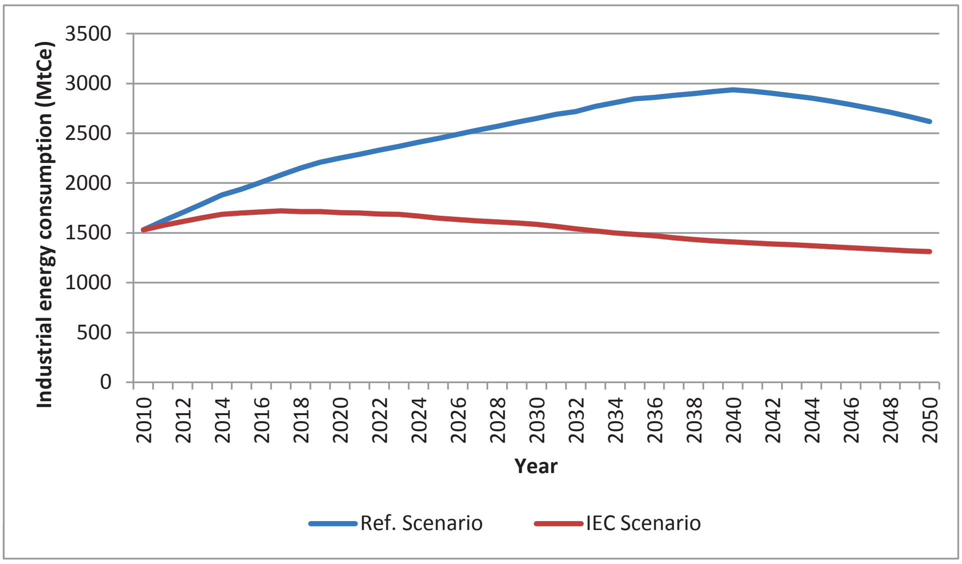
Note: The red parts represent the additional energy efficiency improvement under the Intensified Energy Conservation Scenario on the basis of the Referrence Scenrio

or even higher. Due to the constraints in raw material availability and the small production scales, the potential for improving energy efficiency in the production of aluminum and ammonia is much smaller (see Figure 3-11).

3.2.3 DEVELOPMENT TRENDS IN INDUSTRIAL ENERGY CONSUMPTION

The changes in the energy consumption level of industrial sectors in the two scenarios are shown in Figure 3-12. Under the Reference Scenario, the industrial final energy consumption will continue rapid growth, and the peak value of energy consumption will occur in 2040 at 2.9 Gtce, nearly twice as much as the level in 2010. Under the Intensified Energy Conservation Scenario, with the reduction in the size of energy-intensive industries, the faster development of industries with lower energy intensity and high added values, and the high penetration rates of energy efficient technologies, the industrial final energy consumption will first see slow increase then steady declines. The energy consumption is expected to peak during the 13th FYP period, reaching a peak of only about 1.7 Gtce and the peak will take place twenty years earlier than the peak value under the Reference Scenario.

FIGURE 3-12. The development trends of industrial final energy consumptions under different scenarios



3.3 IDENTIFICATION OF KEY OPPORTUNITIES FOR ENERGY EFFICIENCY AS WELL AS ANALYSIS ON TECHNICAL ECONOMY

China is at the mid-to-late stage of industrialization, when the traditional extensive development mode no longer matches the market environment of supply and demand for factors of production. Therefore, great changes will take place in the tasks and contents of industrial development, and there will be major adjustments in industrial development in the future. In the short run, the development of different industrial sectors will change from one of 'Expanding production capacity and increasing market share' to 'Controlling production capacity, improving energy efficiency and product quality, and environmental protection'. In the medium and long term, China's industry will find a bigger role in social benefits generation and provide greater support for the sustainable development of the whole society. In the whole process of industrial transformation, energy efficiency will play a very important role.

The high impact opportunities for energy efficiency improvement in the industrial sector can be divided into two types: 'technological ones' and 'structural ones', which are described in detail in the following sections.

3.3.1 HIGH IMPACT OPPORTUNITIES FOR ENERGY EFFICIENCY IN THE FIELD OF TECHNOLOGY

There are many sorts of energy-saving technologies in industry, characterized by 'scattered distribution, various classifications and diversified modes'. They not only include technologies in a specific field, but also cross-sector technologies, and not only energy-efficiency equipment, but also production process optimization. Therefore the research group started with setting the criteria for high impact technologies in accordance with the relevant documents issued by government, including *the Catalogue of Key Energy-saving and Low-carbon Technologies for National Promotion (2015), China's Lists of Top-ten Energy-saving Technologies and Top-ten Energy Saving Best Practices, Guidelines for Advanced Applicable Energy Efficiency and Emission Reduction Technologies for the Iron and Steel Industry, and Guideline for Advanced Applicable Energy Efficiency and Emission Reduction Technologies for the Building Materials Industry.* The research team also selected several high impact technologies in order to carry out a technical-economic analysis and assess their promotion potential.

Four criteria are used for the selection of high impact technologies: (1) a high degree of technical maturity and great potential in energy-efficiency improvement; (2) low penetration rate at present, but great potential for promotion in the future; (3) good economic returns for investment; and (4) potential to improve the energy efficiency of the whole society. Based on these criteria, the following high impact technologies are selected for industry (see Table 3-1).

After making a preliminary identification of the high impact technologies in the industry, the research group classified numerous technologies and carried out an analysis and evaluation of four major fields, including waste-heat recovery technologies, advanced combustion/calcination technology, efficient and environmentally friendly boilers and innovative production processes.

Industrial waste-heat recovery technologies

China's industrial sectors abound in waste-heat resources. According to the findings of an investigation conducted by the Energy Research Institute within the NDRC, in 2012, seven industries (including steel, cement, glass, ammonia, caustic soda, calcium carbide and sulfuric acid) were producing waste heat of up to 340 Mtce, accounting for 10% of national total energy consumed in the same year. However, because of technical, economic and conceptual limitations, only some waste-heat resources in China have been developed and utilized. Among the different industrial sectors, the steel industry and the cement industry have higher utilization levels of waste heat, while there is major space for improvement for waste heat use in other industrial sectors. As observed from the perspective of waste-heat temperatures, high-temperature waste-heat sources enjoy higher utilization levels, the utilization of low-to-medium temperature waste-heat sources being more difficult.[6] Intensifying the exploitation and utilization of these resources will be significant for energy efficiency and emission reductions in the industrial sectors of the Chinese economy in the future.

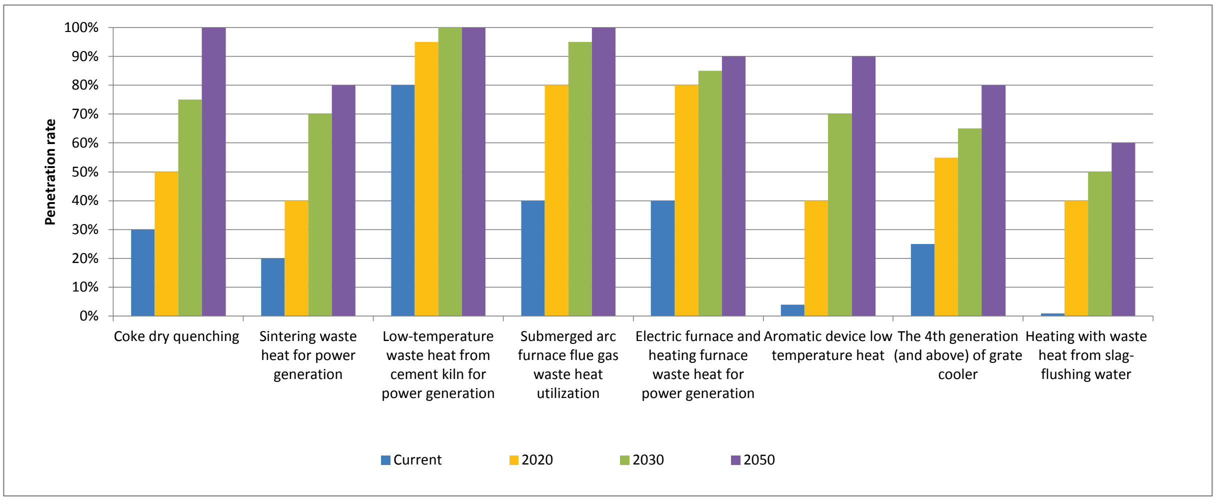
According to preliminary estimates and analysis, the industrial waste-heat utilization technologies that are mature maturity, high economic efficiency and great promotion potential in the market include coke dry quenching (CDQ), sintered ore waste-heat generation, cement-kiln low-temperature waste-heat power generation and slag-washing water heating etc. The predicted future penetration rates of these waste heat recovery technologies are shown in Figure 3-13. Since cement-kiln low-temperature waste-heat power generation technology has been widely deployed among newly built cement plants, there is not much room for further major improvements in penetra-

6 *According to the investigation made by ERI, 54% of industrial waste heat resources are 400°C middle-low temperature waste heat sources, most of which are low-quality waste heat sources with temperature of 200°C and below.*

TABLE 3-1. Summary of key power-saving technologies in the industrial sector

INDUSTRY	MAJOR CRITICAL TECHNOLOGY	INDUSTRY	MAJOR CRITICAL TECHNOLOGY
Iron and Steel	Coal moisture control (CMC) Coke dry quenching technology Sintering waste heat recovery and utilization technology Low temperature sintering technology Mini-pelletized sinter process technology BF top gas dry type TRT technology Converter fume dry dusting technology Converter flue gas waste heat recovery technology Thin slab continuous casting technology Energy management center for steel enterprises	Aluminum	Aluminum cell current intensifying technology New technology for aluminum electrolysis with low temperature and low voltage New type cathode structure aluminum cell technology New type flow-guide structure technology Aluminum electrolysis waste heat recovery technology Aluminum electrolysis anode current distribution monitoring technology Technology for automatic control of aluminum cell roasting
Cement	Pure low-temperature waste heat power generation in cement kiln Fixed grate-cooling machine technology Roller mill technology for raw meal grinding as well as Loesche coal mill technology Vertical mill technology for cement finished grinding Roller press + ball mill combined grinding technology High solid-gas ratio suspension preheating decomposition technology Energy management and control center for cement enterprises	Calcium carbide	Sealed, environment-friendly and energy-saving calcium carbide production technology Low voltage compensation for calcium carbide furnace Calcium carbide furnace tail gas calcined limestone technology Calcium carbide furnace gas direct combustion for steam generation Sensible heat recovery technology Mechanical closed system for automatic loading and proportioning for calcium carbide furnace
Alumina	Technology for production of sand-like aluminum oxide in sintering method Technology for production of sand-like aluminum oxide in Bayer method Sodium aluminate solution seed crystal decomposition technology Alumina calcination waste heat recovery technology Fluidization calcination technology for high efficiency energy saving furnace Automatic filtration technology for refined filtration process	Soda ash	Centrifuge secondary filtration technology Washing water and additive technology for vacuum alkali filter Self-return soda ash steam calcination technology Vacuum distillation technology New technology for soda ash production based on converted gas
Ethylene	High temperature and radiation resistant coating technology for cracking furnace Waste heat recovery, preheating and combustion-supporting air technology Optimization control technology for turbine compressor set	Oil refining	New type whole liquid-phase hydrogenation technology Heat high-pressure separating flow technology Low temperature heat recovery and utilization technology Technology of heat integration and heat feeding between devices
Caustic soda	Membrane (zero) grade distance ion-exchange-membrane electrolysis technology Low tank voltage electrolysis with ion-exchange film Ultrasonic wave scale prevention & descaling technology Technology for optimization control of caustic soda evaporation process Waste-heat utilization technology for hydrogen-chloride synthesis	Ammonia	Pressurized pulverized coal gasification technology Coal water slurry grading gasification technology New type catalyzer used for gas preparation for synthesis ammonia NHD desulfurization and decarbonization technology Pressure swing adsorption (PSA) decarbonization technology in two-section method Alcohol alkylation purification technology Non-power ammonia recovery technology Three Wastes fluidized mix combustion furnace technology Alcohol alkylation purification synthetic ammonia raw gas technology
Copper (5 items)	Oxygen bottom-blown smelting technology Oxygen side-blown bath smelting technology Rotary furnace refining technology Smelting flue gas waste heat recovery technology Automated blowing control technology		

FIGURE 3-13. The penetration rates of major industrial waste-heat utilization technologies in the future (%)



tion rate. In contrast, coke dry quenching (in particular for independent coking plants), sintering waste-heat power generation and the fourth generation of grate coolers have considerable room for penetration rate improvement, which should reach 80% or even higher in 2050.

This research includes a technical and economic analysis by taking coke dry quenching, sinter waste-heat generation and efficient (the fourth generation and above) grate coolers as examples.

(1) Coke dry quenching (high-pressure, high-temperature type)

Technical principle. Coke dry quenching uses inert gases to cool down the coke and recover the waste heat. When pushed out of the coking chamber, the coke falls into the coke pot or coke tank truck used for coke dry quenching and enters the cooling chamber of the dry quenching furnace through the feeding divide. Inert gases are used for heat exchange with coke; the cooled down coke is continuously discharged by the coke discharge device and transferred to the next working procedure. The heated inert gases can enter the waste-heat boiler for heat exchange, steam recovery and power generation, and then the cooled-down inert gases restart the coke-quenching procedure. So-called high-temperature, high-pressure (HTHP) coke dry quenching means that the waste-heat boiler used for coke dry quenching is an HTHP boiler, with the steam flow of the HTHP steam turbine at 100 - 410 t/h, a steam outlet temperature of 540°C and pressure at 9.8 MPa. This technology is applicable to coke furnaces with an annual productive capacity of 0.6 million tons or above, and even to coking plants directly under large and medium steel combined enterprises.

Energy-saving effect. Coke dry quenching technology can recover 80% of waste heat from red-hot coke. On average, it can recover 0.45 - 0.6 ton of steam at 3.9 MPa at 450°C per ton of coke quenched. After the process's energy consumption is deducted, this technology can recover a net energy of 35 - 45 kgce per ton of coke. Under equivalent coke-quenching conditions, the power generation

TABLE 3-2. Division of coke dry quenching investment costs for #6 and #7 coke furnaces in L steel coking plant

NAME OF ENGINEERING COST	ESTIMATED VALUE (10,000 RMB)	PROPORTION IN TOTAL INVESTMENT (%)
Construction engineering	3039	14.34
Equipment and tools/devices	11919	56.24
Installation work fee	2949	13.91
Other capital costs and budgetary reserves	2167	10.22
Dynamic part of construction investment	417	1.97
Liquid fund	704	3.32
Total	21195	100.00

capacity of the steam generated by the HTHP boiler is about 10% - 15% higher than the power generation capacity of the steam generated by a medium-temperature and medium-pressure boiler. Therefore, the HTHP boilers are more energy efficient.

Technical economy. Coke dry quenching transformation and matching power generation project for #6 and #7 coke furnaces of L Steel Coking Plant is selected here as an example (annual coke-processing capacity of 1.1 million tons). This project requires a total funding of up to RMB 211.95 million, and the project investment is divided into several items, as shown in Table 3-2.

A dry-quenching circulatory cooling system can process 1.1 Mt of coke each year. By improving coke quality, this system can recover heat form red-hot coke for reutilization and generate 0.6446 Mt steam at a pressure of 9.5 MPa and a temperature of 540°C each year for power generation. In addition to reducing environmental pollution caused by wet coke quenching, this system recovers substantial heat energy and coke powder of 21600 tons/year, which can be used in production. This system can also improve coke quality and produce remarkable economic and environmental benefits. A waste-heat boiler is used as the steam source, and a set of 25 MW condensed steam turbine generator units is built, with annual power generation of 140 GWh and an annual supply of power of 114.6 GWh, as a result efficient use of resources is realized and the overall benefits to the company are improved. For the purposes of this project, the annual mean production and operation cost is RMB 38.02 million, and the annual average total profit from production is RMB 17.84 million, making an after-tax profit of RMB 11.95 million. According to estimates, the internal rate of return on capital is 9.64%, and the investment payback period (including the construction period) is 8.42 years.

Prospect of promotion. At present, coke dry quenching technology has mostly been used in steel joint production enterprises, but the coke output of these enterprises only accounts for about a third of total national output. Due to small production scale and out-of-date equipment, many independent coking plants have not been equipped with coke dry quenching systems, so that large quantity of waste heat from coke production is wasted each year. On the other hand, the coke dry quenching technology used at present is mainly of the medium-temperature and medium-pressure type, while the proportion of HTHP coke dry quenching in use is only around 30%. With the development of large-scale coke furnaces, HTHP coke dry quenching can produce higher efficiency in waste-heat steam-power generation and thus will represent a future development trend.

(2) Sinter waste heat power generation

Technical principles. Sintering waste heat utilization refers to technology designed for the recovery and reutilization of waste heat generated in the sintering procedure, which is mainly divided into two major forms. The first form is the sensible heat of sintering fumes, which accounts for about 24% of total heat carried in the sintering process. The performance of physical and chemical reactions in the sintering process produces constant changes in the sintering flue gas temperature and contents; when the sintering process enters its final stage, there is an obvious increase in the flue gas temperature, so the temperature of the waste gas discharged from the high-temperature section of the tail bellows can reach 300 - 400°C. The other form is the sensible heat of the sintered ore, which accounts for about 45% of the total quantity of heat carried in the sintering process. The mean temperature of hot sintering mineral discharged from the tail of the sintering machine is 600 - 800°C. In the cooling process, the sensible heat of the sinter is converted into the sensible heat of cooled waste gas, and the temperature of the waste gas in the high-temperature section is 350 - 420°C. Therefore, the fumes at the tail bellows of the sintering machine and the sensible heat of the sinter are the main sources of sintering waste heat recovery.

The fumes introduced from the high-temperature fume sections of the sintering and cooling machines are fed into the top of the waste-heat boiler through the main fume tube and discharged from the lower part of boiler. After heat exchange, the fumes are connected to a blower fan through a pipeline; they are pressurized and then discharged from the funnel, or else the tail gas enters the recirculation and is used for sintering hot blast or sinter cooling air, in this way the flue gas is recycled for heat recovery and utilization. The high temperature fumes discharged from the sintering and cooling machines enter the waste-heat boiler to heat the water in the heating surface; then the water turns into HTHP steam after heat absorption and enters the steam turbine again to generate power, thus forming a combined cycle.

Energy-saving effect. With the adoption of sintering fume waste-heat power-generation technology, after recovery of fume waste heat, for each of sinter production, on average it is feasible to generate up to 20 kWh of power and reduce energy consumption for producing a ton of steel by 8 kgce, thus enabling steel enterprises to achieve significant energy savings and reductions in energy consumption. In general, if waste gas with a temperature of approximately 300°C is used instead of normal temperature air as the combustion-supporting gas for ignition and heat preservation, 25% - 30% of coal and gas consumption can be saved.

Technical economy. Project case: sinter adopts sintering waste-heat recovery technology, with an annual production capacity of 1 million tons. Total investment in this project is RMB 12.23 million, including RMB 12 million of construction costs and RMB 0.23 million of interest incurred during construction. The annual production capacity of the project is 18 GWh of power generation, which can provide RMB 9.18 million of additional income. To add sintering waste heat recovery facilities, the general costs will increase RMB 5.68 million (including power generation costs and the costs of manufacturing, administration, finances etc.), which means a gross profit of up to RMB 3.38 million per year. The investment payback period for this project is estimated at 3.1 years (excluding the construction period), with a financial internal rate of return (FIRR) of 31.9%.

Prospect of promotion. At present, only a small part of the large-scale sintering plants in China are equipped with waste heat recovery and power generation systems, with a 20% take-up rate of power generation technology. It is estimated that the penetration rate of this technology had reached 35% by the end of the 12th FYP period.

(3) Efficient (fourth generation and above) grate cooler

Technical principle. The major function of the grate cooler is to lower the high temperature of clinker with cooling air. In this process, the cold air is heated and the heated air enters the kiln and decomposing furnace in the form of high temperature secondary air and tertiary air before being used for fuel combustion. The high-efficiency grate cooler is provided with a set of inflation grate plates with an air-flow self-adaptation function, which are arranged to form a static grate bed for clinker cooling and air supply. In addition, a set of pushing rods able to perform a reciprocating motion are used to push the clinker layer forward. The high-efficiency grate cooler is characterized by its modular structure, high heat-recovery rate, high transfer efficiency, compact structure, greater energy efficiency and lack of material leakage in the main body.

Energy-saving effect. The power consumption of high-efficiency grate coolers is about 4 kWh per ton of clinker. The high-efficiency grate cooler can achieve a heat recovery rate of 74% or above, being 4% - 6% higher than in the case of the original third generation of grate cooler. Compared to the third generation of grate cooler, the heat consumption of the clinker can be reduced by 60-90 kJ/kg. The volume and the weight of the high-efficiency grate cooler are only a half to a third those of the third generation, and the energy consumption of the equipment itself is also reduced by 20% from that of the third generation. The high-efficiency grate cooler is characterized by high cooling efficiency, long performance life of grid plates, high running rate and obvious benefits in energy efficiency and emission reduction. This product is used for equipment renovation in both newly built and old plants. With 25% of civil engineering investments savings and the maintenance expenses lowered to 70 - 80%, this process can produce significant economic benefits.

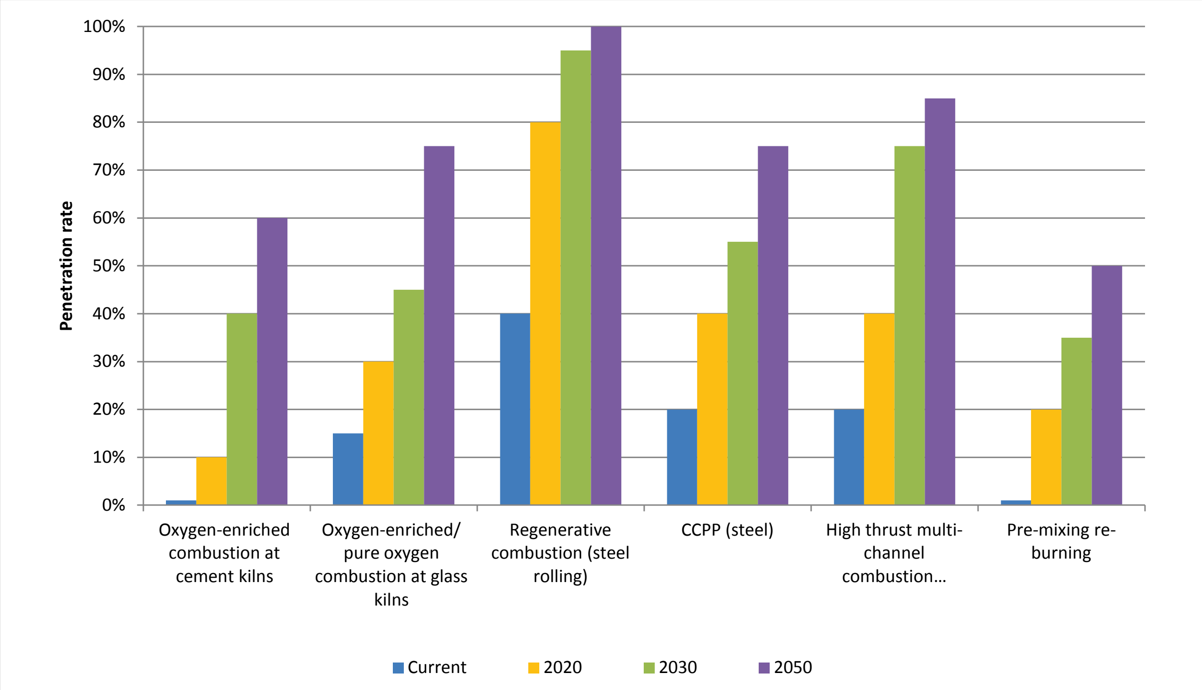
Technical economy. 1) A 3000 ton/day production line is provided with high-efficiency grate cooler technology, with investment costs of about RMB 8 million, a construction period of three months, annual energy savings of 3390 tce, annual economic benefits from energy efficiency of up to RMB 2.37 million and an investment payback period of 3.5 years. 2) A 5500 ton/day cement production line is provided with high-efficiency grate cooler technology, with investment costs of RMB 10 million, a construction period of three months, annual energy savings of 5330 tce, annual economic benefits from energy efficiency of up to RMB 3.7 million and an investment payback period of three years. 3) In the example of a 5000 ton/day (1.5 Mt/year) cement production line, the investment in a high-efficiency grate cooler is about RMB 20 million, and the operational and maintenance costs are about 5 million RMB/year. This project can save up to 4000 - 4500 ton of coal each year, with an investment payback period of 3-5 years.

Prospect of promotion. The market penetration rate of this technology is approximately 25% at present, and is estimated to reach 55% in 2020, 65% in 2030 and 80% or above in 2050.

Advanced industrial combustion/calcination technology

With the advancement of combustion technology and equipment, one important solution of industrial energy efficiency improvement is to increase fuel-use efficiency by improving combustion conditions and modes. For example, oxygen-enriched combustion or total oxygen combustion technology is adopted in the building materials industry (cement and glass); regenerative combustion technology is used in steel and nonferrous metal industries; and blast furnace gas with a lower heating value, gas-steam combined cycle power plant (CCPP) technology and stratified combustion technologies are applied in the steel industry. Estimates of the penetration rates of the said technologies in the future are shown in Figure 3-14. Since the regenerative combustion technology is more cost effective and has a realistic basis for technical application, its penetration rate is expected to improve from 40% at present to approximately 70% by 2020. Oxygen-enriched combustion technology is deployed more quickly in the glass and ceramics industries than in the cement industry. However, by 2050, the penetration rate for this technology in the building materials industry is expected to reach 60% or more. Since CCPP is constrai-

FIGURE 3-14. The penetration rates of major industrial efficient combustion technologies in the future (%)



ned by the scale of production and the residual blast-furnace gas volumes of steel plants, there is more uncertainty in the promotion of this technology. However, with the improvements in the production concentration of the steel industry and progress in blast-furnace gas-recovery technology, the CCPP penetration rate is expected to increase to about 70% by 2050.

In the following section, cost-benefit estimates and analysis will be made by taking oxygen-enriched combustion technology and regenerative combustion technology as examples:

(1) Oxygen-enriched combustion technology

Technical principle. Oxygen-enriched combustion technology can be described as a secondary revolution in the field of combustion. Its principle is to improve the concentration of oxygen in the air (oxygen concentration is generally increased to 28 - 30%), so that the volatile contents and the unburned carbon particles in the fuel are sufficiently burned in the oxygen-enriched air. This technology can improve the flame temperature by 100-350°C, speed up the combustion process and rapidly improve thermal radiation. It is designed to strengthen combustion, reduce the excess air coefficient, reduce the air displacement and dust volume after combustion, decrease the carbon dioxide content, improve combustion efficiency, effectively convert the fuel in oxygen-enriched combustion into heat energy, and thus effectively improve the combustion efficiency of the fuel.

Energy-saving effect. For the purposes of oxygen-enriched combustion, the oxygen-enriched gas with an oxygen content of more than 21% is used as the combustion-supporting air. The specific oxygen concentration varies in the different industrial sectors and enterprises. For example, in the cement industry, by improving the oxygen concentration to 28% - 30%, it is feasible to reduce the temperature of the ignition point, speed up the combustion velocity, increase the flame temperature, achieve more complete combustion, reduce the emission of waste gas, reduce the heat quantity carried by flue gas, and improve the thermal efficiency, thus saving energy by about 10%.

Technical economy

Case 1. A cement manufacturer makes a technical change to its rotary kiln by using oxygen-enriched combustion technology and the additional equipment is a membrane method-based oxygen-producing device. According to the actual operational effects, after process change, the coal-saving ratio may reach 8-12%. Based on conservative estimates (a coal-saving ratio of 8% and an annual coal consumption of 0.276 Mt), this project can save the enterprise 22,080 tons of raw coal consumption annually, or 15,771 tce. Since the price of raw coal is 620 RMB/ton, this can lead to an annual coal cost saving of 22,080 ton×620 RMB/ton =13,689,600 RMB. In addition, the annual actual power consumption of oxygen-producing equipment is 7,920,000 kWh, the power rate is 0.61 RMB/kWh, the annual electricity cost is 7,920,000 kWh×0.61

RMB/kWh = 4,831,200 RMB. As a result, the oxygen-enriched combustion technology can generate a cost saving of 13,689,600 RMB - 4,831,200 RMB = 8,858,400 RMB for the enterprises through energy efficiency improvement.

Case 2. A cement plant introduces a technical innovation to its 3000 ton/day production line by using membrane rich oxidation combustion-supporting technology, with a total project investment of RMB 3.85 million and the power of the oxygen-producing equipment being 412 kW. When the energy use during the three months prior to the introduction of oxygen enrichment is compared with the energy use during the 50 days after oxygen enrichment is used, the average energy efficiency improvement exceeds 5.0%. This leaves to an annual coal saving of 130,000×5% =6500 tons; at a coal price of 600 RMB/ton, this leads to a reduction in coal costs of RMB 3.9 million. The annual power consumption cost of the equipment is RMB 1.3 million. Hence the enterprise can obtain a economic benefit of RMB 3.9 million – RMB 1.3 million = RMB 2.6 million from energy efficiency improvement by using oxygen-enriched combustion technology.

Prospect of promotion. Since the cement industry has just started using oxygen-enriched combustion technology, the market penetration rate of this technology is less than 1% at present, but it can be improved to about 10% by 2020, to 30% by 2030 and to 50% above by 2050. In the glass industry, the penetration rate of oxygen-enriched combustion technology is expected to reach 30% by 2020.

(2) Regenerative combustion technology

Technical principle. Regenerative combustion technology is a flue gas waste heat recovery technology, with high-temperature air-combustion technology at its core. High-temperature flue gas is used to preheat combustion-supporting air and/or coal gas. When the air-preheating temperature reaches 1000°C, air with an oxygen concentration of 2% is combustible; in other word, the higher the air-preheating temperature, the lower the minimum oxygen concentration to keep combustion stable. When fuels combust in a poor-oxygen environment, the combustion process is a diffusion control-type reaction. In comparison with the traditional combustion phenomenon, the distance from the root of the flame to the combustion nozzle is reduced, the common flame incandescence zone disappears, and the volume of the flame zone multiplies and can even expand to the whole hearth. At this moment, the whole hearth becomes a black body for high-temperature intense radiation with a relatively even distribution of temperature (the minimal temperature difference can be reduced to 10°C). As a result, the heat-transfer efficiency of the hearth is significantly improved and the NO_x emissions can be reduced by dozens of times, hence energy efficiency and environmental protection can be achieved.

Energy-saving effect. By applying the regenerative combustion technology to the steel rolling heating furnace, it is feasible to cool of the high-temperature flue gas discharged from the heating furnace to below 150°C, thus achieving a heat-recovery rate of 85% or above and an energy-efficiency rate of 30% or above. It is feasible to preheat air and coal gas to 700 - 1000°C and reduce the oxidation burning loss, so that the rate of loss is less than 0.7%. By preventing poor-oxygen combustion, this technology can greatly reduce the NO_x in flue emissions by more than 40%. In addition, thanks to its outstanding energy-efficiency improving effect, emissions of CO_2 can be reduced by 10%-70%. In the heat-storage mode, the regenerative combustion technology can realize the maximum recovery of waste gas heat generated by the heating furnace and preheat the combustion-supporting air and coal gas to a high temperature, thus greatly improving the heat efficiency of the heating furnace, leading to a 10% - 15% increase in production efficiency. In addition, the low calorific value fuels (such as blast furnace gas, generator gas, low calorific value solid fuels and low calorific value liquid fuels) may achieve a higher temperature of combustion with the aid of high-temperature preheated air, so that the application range of low-calorific value fuels is enlarged.

Technical economy. *Project case.* A steel rolling heating furnace with an annual productive capacity of a million tons is equipped with regenerative combustion technology. The total investment of this project is RMB 10.18 million, including RMB 10 million of construction investment and RMB 0.18 million of interest incurred during construction. The project leads to an energy saving of 10 kgce per ton of steel and can generate RMB 17.09 million of energy cost saving annually. Applying the regenerative combustion technology leads to increases in depreciation costs, maintenance expenses management expenses and financial expenses and the total additional expenses is RMB 2.3 million and the project's annual gross profit is RMB 14.47 million. It is estimated that the investment payback period of the project (not including the construction period) is one year, and the financial internal rate of return is 107.8%.

Prospect of promotion. The penetration rate of this technology is about 40% by 2010, and its deployment ratio is expected to reach 70% by 2020, 95% by 2030 and 100% by 2050.

3.1.3 HIGH-EFFICIENCY AND ENVIRONMENTALLY FRIENDLY INDUSTRIAL BOILERS

In 2010, 584,700 boilers were in use in China, the average capacity of boilers had increased from 2.4 t/h before 1990 to the present 5.8 t/h, and the annual consumption of raw coal is about 640 million tons (450 Mtce), accounting for 15% of national total energy consumption (CNIS 2015).

There are about 490,000 coal-fired industrial boilers, and mechanized laminar-burning boilers account for more than 70% of the capacity of all coal-fired industrial boilers. 60% of the laminar-burning boilers are chain-grate boilers, the major type of industrial boiler combustion equipment.

Through efforts over many years, the energy efficiency level and emissions index of China's industrial boilers have gradually been improved, but there are still gaps with the corresponding values in the developed countries. The average operating efficiency of China's coal-fired industrial boilers is 65% - 70%, 10 - 20% lower than the most advanced international level, and the emissions of pollutants remain high. In 2012, industrial boilers emitted about 4.1 million ton of smoke dust, 5.7 million tons of sulfur dioxide, and 2 million tons of nitrogen, accounting for 32%, 26% and 15% of total national emissions respectively.

For a very long period into the future, coal-fired industrial boilers of medium-to-large capacities (unit set steam output ≥ 10t/h) will continue being widely used in China. However, coal-fired boilers produce serious environmental pollution. With the changes in energy supply structure and the increasingly strict requirements for energy saving and environment protection, the development and use of natural gas will speed up and small coal-fired industrial boilers will be removed from central urban areas. Some boilers using clean combustion technology, such as circulating fluid bed boilers, will witness high-speed development. Gas-fired boilers will see rapid expansion, while the boilers combusting domestic garbage and biomass enjoy enormous market potential. Therefore, the high-efficiency, energy-saving and low-pollution industrial boilers based on clean fuels and clean combustion technologies will represent the development trend of industrial boilers.

(1) High-efficiency pulverized coal fired boiler

Technical principle. Pulverized coal-fired boilers are suspension combustion boilers using coal dust as their fuel. In these boilers, the hearth is a large enclosure with water-cooled hearth fireplace walls. After mixed with air through the spray burner, pulverized coal (particle diameter of about 0.05-0.1 mm) is sprayed into the hearth for combustion. The combustion of pulverized coal is divided into a preparation stage prior to ignition, a combustion stage and an after-combustion stage. Based on such advanced technologies as concentrated preparation of pulverized coal, precision powder supply, air-staged combustion, in-furnace desulfurization, boiler shell (or water tube)-type boiler heat exchange, efficient bag-type dust removal, flue gas desulphurization and denitrification, as well as an entirely automatic control, high-efficiency pulverized coal-fired boilers can achieve high operation efficiency and low emissions.

Energy-saving effect. The new type of high-efficiency pulverized coal-fired boiler technology can achieve a coal combustion rates of 98% and boiler heat efficiency rates of 90% or higher, thus 30% less coal use than traditional coal-fired boilers. By using the new type of high-efficiency pulverized coal-fired boiler technology, it is feasible to save the annual fuel costs by more than 20% against the usual coal-burning boiler technology and by more than 70% against the oil-burning boiler technology. In addition, the emission of smoke dust (TSP) is less than 20 mg/ Nm^3 (the national standard is 100 mg/ Nm^3), and the SO_2 emissions are less than 500 mg/Nm^3 (the national standard is 900 mg/ Nm^3). Various technical indicators have reached advanced international levels.

Technical economy. In spite of a slightly higher unit price (due to the necessity to turn coal into pulverized coal), high-efficiency pulverized coal-fired boilers still have better technical economy that traditional coal-burning boilers due to their higher combustion efficiency and heat efficiency. According to tests conducted by the Coal Science Research Institute, to generate a ton of steam, the pulverized coal-fired boiler only requires 111 kg of pulverized coal, while the traditional chain-grate boiler requires 188 kg. If unit set operation efficiency is 20t/h and the annual operation duration is 6000 h, the annual fuel cost for the operation of pulverized coal-fired boilers is RMB 14.66 million, much less than the RMB 18.11 million for traditional chain grate boilers.

Prospect of promotion. At present, the market share of high-efficiency pulverized coal-fired boiler systems is less than 1%. Assume these boilers can replace 20,000-30,000 sets of existing small and medium-size coal-burning boilers (average capacity 6 t/h) and that boiler hot efficiency is improved by about 25%, it can help China save 9 million tons of coal consumption each year, reduce 0.5 million tons of SO_2 emissions, reduce 50,000 tons of dust emissions, and greatly reduce the emissions of inhalable particles, thus producing significant energy-efficiency and environmental benefits (Fan 2012). The penetration rate of this technology in industries is expected to reach 10% by 2020, 25% by 2030 and 35% or above by 2050.

(2) Coal water slurry boiler

Technical principle. The coal water slurry boiler uses coal water slurry as a fuel for combustion. Coal water slurry is a new coal-based liquid fuel, in which coal accounts for 70%, chemical additives for about 1% and water for the rest. Coal water slurry can be stored in the same manner as petroleum, can be transported through pipelines and has the performance of highly efficient combustion. In addition, it is characterized by fewer emissions, good sa-

fety features, strong stability and lower prices. As an ideal alternative fuel that can replace oil and coal, coal water slurry can be extensively used in civil and industrial boilers and is an internationally recognized clean-coal fuel. China has completed engineering tests and production operations on the use of coal water slurry for combustion in multiple types of boilers and furnace kilns, including industrial boilers, power plant boilers and industrial furnaces (steel rolling heating furnaces, annealing furnaces, calcination furnaces, tunnel-drying furnaces, ceramic spray-drying tower hot-blast furnaces, and tunnel-sintering kilns for brick manufacture and ceramic wares) (Liu 2014).

Energy-saving effect. A coal water slurry boiler can achieve even efficient utilization of coal resources, so that the heat efficiency of the boiler system can reach 85% or above, and the burn-off rate 97% or above. By using a coal water slurry boiler instead of a traditional coal-fired steam boiler, it becomes feasible to reduce coal consumption. Furthermore, with respect to environmental protection, since coal water slurry contains about 30% water content, the combustion temperature of slurry is lower than the pulverized coal flame temperature by 150°C; The water vapor in coal water slurry generates a producing action in the combustion process and thus reduces NO_X into N_2 components, so that exhaust emissions of nitrogen oxides are greatly reduced. According to actual findings, the emissions of smoke dust, sulfur dioxide and nitrogen oxides discharged from coal water slurry boiler are only 70%, 15% and 39% respectively of the emissions discharge from the traditional coal-burning boiler (Yi et al. 2012).

Technical economy. Many scholars have conducted comparison analysis on coal-fired steam boilers and coal water slurry steam boilers in terms of their economic efficiency. The results indicate that to produce the same scale of steam, and taking such costs as fuel, labor, operation and maintenance into comprehensive consideration, coal water slurry steam boilers have an annual costs 10-15% than traditional coal-fired steam boilers. If the economic benefits of pollutant emissions reduction are also taken into consideration, the economic benefits of coal water slurry boilers will be even more significant (Liang et al., 2012). Furthermore, coal water slurry boilers have high combustion adjustability, are simple and convenient to control, can realize stable combustion under low load, and are even suitable for operating conditions characterized by load fluctuation.

Prospect of promotion. Given the increase in energy demand and the increasingly strict requirements for environmental protection, it is estimated that the installed capacity of coal water slurry use will increase 5 million tons per year. Based on an oil substitution quantity/ coal substitution quantity ratio of 1:9, it is estimated that, by 2015, 2020 and 2030, annual coal water slurry use will reach 55 million tons, 80 million tons and 130 million tons respectively and the annual oil savings will be 2.2 million tons, 3.2 million tons and 5.2 million tons. The annual SO_2 emission reductions will be respectively 201,300 tons, 292,800 tons and 475,000 tons; the annual cost savings will reach RMB 8.84 billion, RMB 12.85 billion and RMB 20.86 billion (Liang et al. 2012).

3.1.4 OPTIMIZATION OF PROCESS ROUTE AND OPTIMIZATION OF ENERGY USE MODE

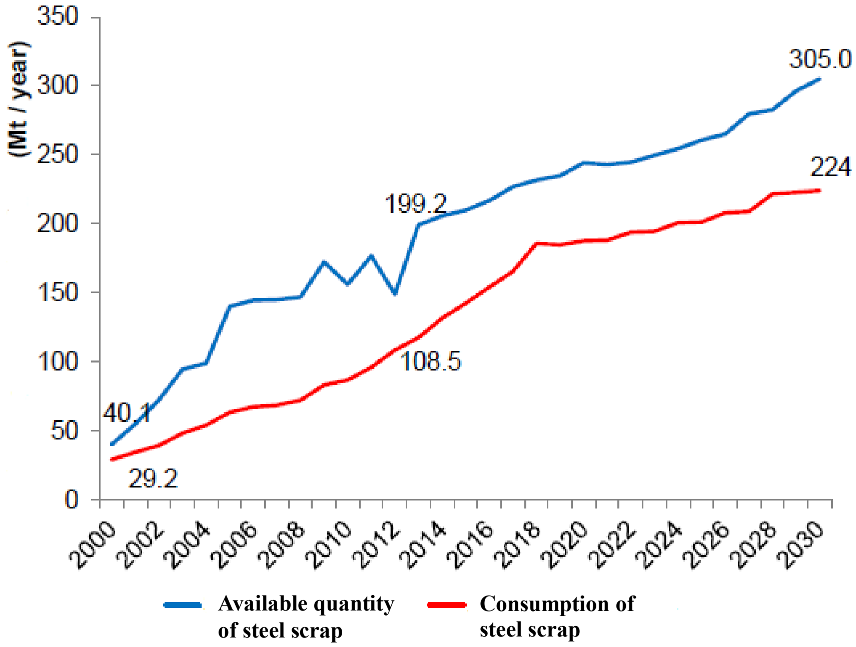
The innovation of production processes and the substitution of fuels belong to solutions for energy efficiency improvement in the broad sense. Since these measures can fundamentally change the efficiency of energy utilization in industrial production, they constitute another important field for improving industrial energy efficiency in the future. For example, when the short process of electric furnace steelmaking is used to replace the long process of converter steel-making, energy consumption for producing a ton of steel can be reduced by more than 70%. And when a natural gas boiler is used to replace the traditional coal-burning boiler, energy efficiency can be improved by nearly 30%, and pollutant emission can also be significantly reduced.

(1) Use short-process steel-making to replace long-process steel-making

Steel production uses two types of basic process flows. The first type is the blast furnace - converter - hot rolling - deep processing flow, with iron ore and coal as raw materials, called the long process flow. The second type is the electric furnace - hot rolling - deep processing flow using steel scrap as raw material, called the short process flow. For the production of 1 ton of crude steel using the short process instead of the long process, it is possible to save 1.3 tons of fine iron powder, reduce energy consumption by 350 - 450 kg coal equivalent (an energy saving of 74%) and reduce emissions of carbon dioxide by 1.4 ton or 58% (China Iron and Steel Association 2015). Furthermore, 80% of energy resources consumed in long-process steel-making are coal resources, while the energy resource consumed in short-process steel-making is entirely electric power. Therefore, the increase in the steel-scrap use scale is important in saving resources, reducing energy consumption, including coal, reducing the consumption of raw materials, decreasing environmental pollution, cutting the costs and increasing employment.

Sources of steel scrap include staple commodities such as spent automobiles, spent machineries, obsolete vessels and waste appliances, the cutting steel scrap from

FIGURE 3-15. **The available quantity and consumption of steel scrap in China in 2000-2030 and relevant predictions**



Data source: World Steel Association Report on the Energy Efficiency Potential in the Utilization of Steel Scrap (2012)

machining processes in machinery manufacturing and self-made steel scrap such as top crops and tank bottoms produced in steel mill production. In the future, the generation and utilization quantities of domestic steel scrap in China will be closely related to the domestic steel production level, the mean life of steel products and the effective planning of scrap recovery. The World Steel Association has estimated the available quantity of steel scrap and scrap consumption in China in the future (as shown in Figure 3-15). Due to continuous industrialization development, available steel scrap resources will constantly increase, reaching 250 million tons in 2020 and exceeding 300 million tons in 2030.

With the increase in available quantities of steel scrap, prices for it will fall, which is favorable to increasing the proportion of electric furnace steel output and optimizing the process route for steel production. In 2014, the proportion of China's electric furnace steel yields was 12%. This value is expected to increase to about 16% - 18% by 2020, reach 25% - 30% by 2030 and 40% or above by 2050.

(2) Promoting coal-to-natural gas and coal-to-electricity fuel switch projects

In developed countries, the proportion of coal consumption in industrial end energy use is generally 10% or even lower. In contrast, coal has thus far played contributed the majority of China's industrial energy consumption, the proportion of coal use remaining at 50% or above for a long period of time.[7] As the major equipment for industrial coal consumption, industrial boilers and kilns, which are small in scale and widely scattered, result in low energy efficiency and high environmental pollution.

The terms 'coal-to-gas' and 'coal-to-electricity' refer to the utilization of natural gas and electricity to replace coal consumption. They are both important approaches to reducing the end-use of coal and thus reduce environmental pollution. For example, SO_2, NO_x and dust emissions discharged from gas-fired boilers are respectively 1.7%, 15.8% and 8.7% of the emissions from coal-burning boilers (Chinese Academy of Sciences, 2012). The pollutant emissions from natural gas combustion are remarkably lower than coal combustion. Electric boilers hardly generate any pollutant emissions in their use; they also enjoy such multiple advantages as small space requirements, noise-free performance, high heat efficiency, and simplicity in installation, operation and maintenance.

Existing projects have proved that the fuel switch from coal to natural gas in the ceramic and glass industries can produce outstanding environmental benefits and can improve product quality and technological level. Therefore, it is necessary to promote coal-to-gas technology upgrade in these industrial sectors. For example, a glass plant lo-

7 *The coal consumption mentioned here includes the consumption of raw coal, cleaned coal, other washed coal and coke.*

cated in Xingtai City, Hebei Province, has switched from coal to natural gas; as a result, its annual coal consumption is reduced by nearly 65,000 tons, emissions of sulfur dioxide by 275 tons, emission of nitrogen oxides by 190 tons, and emission of smoke dust by nearly 32 tons. Furthermore, this glass manufacturer also uses natural gas to produce glass ceramics with high added values. The market price of glass ceramics is tens of times that of ordinary glass.[8] In the future, natural gas use will become an even more attractive option due the reform of gas pricing mechanisms and stable supplies of natural gas, coal-to-gas technology switch will become a strategic option for the low-carbon development of industry which is both feasible and profitable.

The coal-to-electricity technology switch involves an induction heating technology used for metal materials, featuring high heating efficiency, high heating speed and low energy consumption. Furthermore, electric heating can realize the automatic and remote control of temperature, and therefore enjoy extensive application potential in many industrial sectors. For example, in heating furnace equipment with low temperatures and moderate heating volumes in the building materials sector, coal-to-electricity technology upgrade can remarkably improve the heating efficiency of furnaces as well as the finished product ratio and quality of products, generating enormous economic benefits. It is worth mentioning that, if heat-accumulating electrical boilers are used to replace coal-burning boilers, it can convert electric power into heat energy for storage in time of low power load and benefit from low power prices during low-load periods, so as to achieve the 'win-win' results of both economic benefits and social benefits.

3.2 HIGH IMPACT OPPORTUNITIES IN INDUSTRIAL STRUCTURE OPTIMIZATION

3.2.1 THE 'DE-CAPACITY' AND TRANSFORMATION OF ENERGY-INTENSIVE INDUSTRIES

Under the combined actions of periodical, structural and systematic factors, China's excess production capacity problem has started to spread from traditional industries to emerging industries. Statistics indicate that in 2014 the average utilization rate of industrial productive capacity was only 75%, the lowest level since 2009; the capacity utilization rates for crude steel, cement and coke production were 70% or even lower. In addition to serious excess capacity in traditional industries, in recent years some emerging industries, such as solar PV and LED, are also increasingly facing excess capacity issues, which will inevitably result in decreases in profit rates for industries and enterprises, while low-level price competition will cause a decline in the overall benefits of industrial development.

In fact, the excess capacity problem in China is a 'structural issue', namely the excess productive capacity of low-quality products, with supply far exceeding market demand (see Figure 3-16). On the other hand, the market increasingly demands for high-quality and high value-added products, which are in seriously short supply. Therefore, China has to rely on imports to meet market demand. For example, China's steel production accounts for nearly half of the world total, but the Chinese steel industry mainly produces low-quality products. Due to excess competition, the profit margin of these ordinary steel products is very small. In contrast, high value-added steel products enjoy high selling prices and profits. However, for technical reasons, the domestic production of high value-added steel products is very small, therefore China has to import such products from Japan and Germany at high prices.

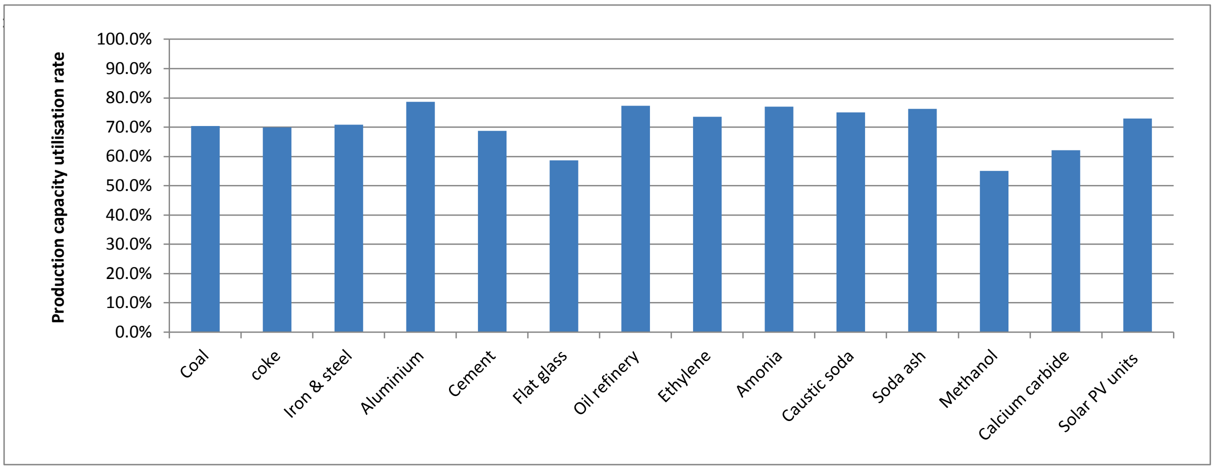
The primary tasks with which energy-intensive industries will be confronted in the future include 'de-capacity' and transformation. 'De-capacity' is a painful process that industries and enterprises have to undergo to eliminate the excessive capacity. The low-quality and low value-added production capacities have to be eliminated in order to make capital, labor and land available for enterprise development. Meanwhile, to remove the market gaps caused by structural surpluses and shortages, enterprises will have to attach greater importance to investment in R&D and analysis of market demand, expand their product mixes towards the high end of the industry chain and both ends of the 'Smile Curve', and adjust and upgrade their product structure in response to market changes.

3.2.2 INDUSTRIAL 'ECO-LINK' DEVELOPMENT MODE

Apart from promoting advanced energy-efficiency technologies, developed countries are also making efforts to explore the social outreach effects of industrial enterprises, open up the physical boundaries of industrial plants, and establish 'eco-links' with different sectors and fields within the whole of society. One concrete measure is recovering the residual heat, residual pressure and excess materials generated in the production processes of industrial enterprises and using them in the household living and commercial fields, thus achieving the savings of energy and resources at a greater, broader and higher level.

8 *The marketing price of common glass is less than 10 RMB/m2, while that of glass ceramics is up to 280 RMB/m2.*

FIGURE 3-16. The capacity utilization rates of major energy-intensive industries (2014, %)



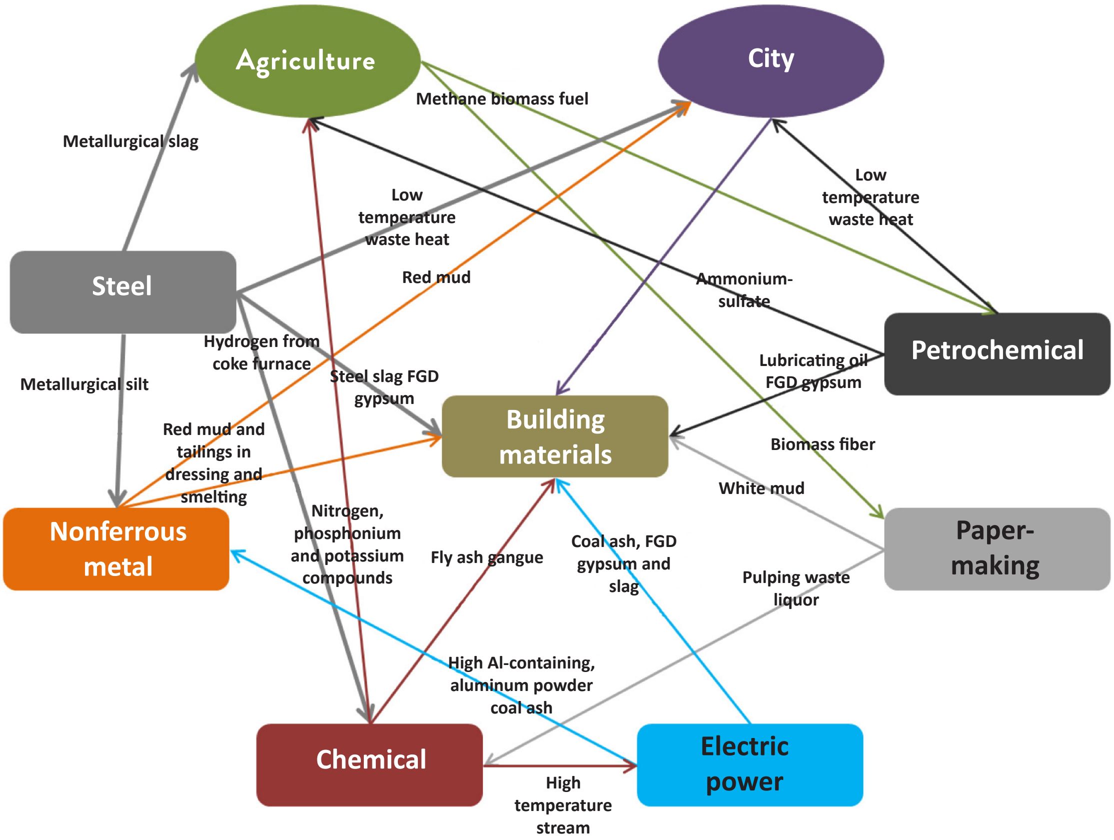
Data source: Qingyi WANG, 'Energy data 2015'

If the boundaries of industrial enterprises can be opened up and an industrial 'eco-link' established in accordance with the characteristics of the participants, the industrial energy efficiency improvement will develop from individual enterprise's optimum effect to society's overall optimal effect, genuinely achieving the 'best use of everything'. As shown in Figure 3-17, in the entire social 'eco-link' system, large quantities of low-temperature waste heat generated by steel enterprises in the production process can be used for the space heating of nearby residential and commercial buildings, while coke-oven gas is an ideal raw material for nearby chemical enterprises. Many waste materials and wastes generated in paper-making and the chemical industries can be used in agriculture. The social outreach effects of cement factories are significant, since the wastes generated by such sectors as power generation, steel, coal and chemical engineering can be used for the production of cement. On the other hand, cement kilns can be used to treat municipal wastes and sludge; hence the industrial eco-link development mode is superior to traditional processing methods such as waste incineration in terms of cost benefits and environmental effects. Since this mode of development for city and industry integration and construction of the composite factory can not only improve the efficiency of energy utilization and the economic efficiency of products in a broad sense, but also address such problems of urban development as garbage and sewage treatment to a considerable extent, there will be more space for its development in the future.

Technical principle. The technical principle for using cement kilns to co-process combustible waste is not complex. After garbage preprocessing, the waste is sorted or the heat generated by different types of garbage incinerator (including gasifiers) is used and the combustible wastes are sent to the decomposition furnace for combustion; the combustible wastes can replace some fuel consumption. The advantages of this method are that, due to the high temperature, alkaline environment, high thermal intensity and long duration of combustion in a cement rotary kiln, using the cement kiln to co-process domestic garbage can avoid the generation of dioxin. In addition, the incineration ashes to be used as feed-proportioning materials enter the cement clinker through calcination, or else are used as blending materials mixed into the cement product. By using cement kilns for the incineration of urban domestic garbage and the co-processing of hazardous wastes, it is feasible not only to make full use of the heat value of garbage to replace coal combustion, but also to address the problem of garbage disposal. For the future, this technology will be an important direction in the transformation and development of cement enterprises.

Energy-saving effect. As compared with other methods for processing wastes, the use of cement kilns for co-processing domestic garbage and different kinds of waste has advantages in terms of energy-saving, environmental protection and economic efficiency. Rough calculations show that if a new or existing cement production line is used for co-processing garbage, investment in this solution is lower than investment in building new waste incineration power plants at the same waste processing scale. Furthermore, domestic garbage can replace some of the raw materials and fuels used in cement production. For example, Anhui Conch Cement Company located in Tongling has built a 5000t/d cement clinker production line based on garbage combustion. With a daily capacity of burning 300 - 600 tons of garbage, this cement clinker production line can save 13500 - 27000 tce of energy use annually (the exact quantity depends on the heat value of garbage).

FIGURE 3-17. **Industrial 'ecological linkage' development mode**



Technical economy. Since different garbage-combustion based cement production lines have their own features and the garbage can also vary, their investment requirements and economic returns are also different. One example is the Tongling Conch Cement. This project is based on the dry-process cement clinker production line of Tongling Conch Cement Company, which has a daily cement production capacity of 5000 tons; it has a daily garbage processing capacity of 600 tons and an annual processing capacity of up to 0.2 million tons. This project was started in October 2008 and was officially completed and put into service in 2010, with a total project investment of RMB 160 million. The total cost of processing a ton of garbage is RMB 200, and the enterprise can obtain allowances worth RMB 190 from the local government for the combustion of each tone of garbage. Based on a daily garbage-processing capacity of 300 tons, this project can save 13500 tce of energy comsuption annually. Another example is the Jiangsu Liyang Tianshan Cement Plant. The Liyang Domestic Garbage-Processing Project can process 450 tons of urban domestic garbage daily and has an annual processing capacity of 164,300 tons. Sinoma International Engineering Co., Ltd and Xinjiang Tianshan Cement Co., Ltd are joint investors of this project. For this project, the investment in garbage-processing capacity is 636.51 RMB/ton; the electricity consumption for the processing is 29.91kwh/ton; the unit cost of garbage processing is 74.04 RMB/ton; and this project can save 3 hectares of land for waste landfilling each year.

Prospect of promotion. Compared with the other ways of waste disposal, using cement kiln co-processing to combust domestic waste has advantages in terms of energy efficiency, environmental protection and economic returns. It can partially replace the fuel and raw materials required for cement production, reduce the consumption of natural mineral resources, help the low-carbon development of the cement industry, and save the land use for garbage disposal and land filling. Therefore, using cement kilns for the co-processing of domestic garbage and various wastes is an internationally accepted approach for garbage disposal. At present, the penetration rate of the cement kiln co-processing of domestic waste is only 1%, but it is expected to reach 10% by 2020, 25% by 2030 and 45% or above by 2050.

3.2.3 EMERGING DISRUPTIVE TECHNOLOGIES

At present, the whole world is planning a new industrial revolution based on artificial intelligence, digitization

and networking. Disruptive technologies represented by 3D printing, industrial robots and cloud computing will not only change the modes of industrial production and the forms of industrial organization, but also create industrial sectors with significant opportunities for improving the efficiency of energy and resource utilization.

Driven by revolutionary technical breakthroughs in such fields as the Internet, information communication and transfer, and intelligent control, information network technology and traditional manufacturing industries have achieved mutual penetration and in-depth fusion. The changes in production modes, including material additive manufacturing and digitized embedded production, will produce active influences on industrial sectors for improving product quality and reducing energy consumption. On the one hand, intelligent and refined industrial production greatly save the consumption of energy and raw materials and improve the utilization efficiency of energy. For example, the 'material additive manufacturing' mode represented by 3D printers can reduce raw material consumption by 80% and even realize zero waste production. Cyber-physical systems (CPS) can change the production environment in real time and achieve the optimal matching of conditions such as temperature, humidity and pressure in industrial processes. On the other hand, the most important function of the new industrial revolution is to realize the large-scale production of individualized products. 'Personally tailored' products will replace mass products manufactured on streamline. This means that the competitiveness and added values of end products will be substantially improved, while significant increases in economic efficiency in energy utilization will also be achieved.

In 2015, the Chinese government issued 'Made in China 2025', which specified the dominant position of industry in the nation's future economy and established a vision for industrial transformation and development and for adapting to and leading the world's new industrial revolution. In order to achieve transformation and development and further improve energy efficiency, China's industrial sectors are expected to make full use of the technological dividends released from the Internet, big data and cyber physical systems. With the support of new technologies such as information, communication and intelligent control, China's industrial sectors should pursue fundamental transformations in industrial production modes and organizational forms, realize the transition from local single-point processes to systematic optimization to entire process flows, and 'leapfrog' development. By applying precision control and automation technologies, China's industrial sectors will promote the standardized and procedure-based management of production processes, improve production quality, reduce defect rates, and thus reduce the waste of raw materials and energy sources. Through system integration and the development of embedded software, China's industrial sectors will optimize the production links or management modes of enterprises, realize the automation and integration of design and production, shorten the process flows and improve production efficiency. Accordingly, the efficiency of resource and energy utilization in relevant industries will be significantly improved, while progress with the transformation from traditional industries to modern, intensive and efficient industries will be greatly promoted.

3.3 ANALYSIS OF THE ENERGY-SAVING POTENTIAL OF HIOS

Under the Reference Scenario, in 2050, industrial final energy consumption will exceed 2.6 Gtce. However, under the Intensified Energy Conservation Scenario, final energy consumption will be only 1.3 Gtce, 15% lower than the level of 1.5 Gtce recorded in 2010. The industrial sectors will reach leading global levels in terms of energy and resource efficiency, intelligent manufacturing and pollutant disposal capacity. As shown in Figure 3-18, among the 'high impact opportunities for energy efficiency' in the industrial sector, four are technology-based opportunities, namely waste heat recovery, advanced combustion/calcination, high-efficiency and environmentally friendly boilers and process-route optimization, will have combined energy-saving potential of 580 Mtce. Three HIOs are structure-based opportunities, namely de-capacity and transformation development, industrial eco-link and the application of disruptive technologies, will have a combined energy-saving potentials of 490 Mtce. In conclusion, in the future implementation of energy saving actions, the industrial sectors should attach equal importance to both technology-based and structure-based energy-saving opportunities. While promoting advanced technologies and equipment to improve energy efficiency, the industrial sectors should also devote more efforts to industrial structure adjustment and product structure optimization, as well as to improvement in production processes and modes of industrial development, so as to improve social benefits.

3.4 POLICY RECOMMENDATIONS

Although many energy-efficiency technologies have good investment returns, they have failed to receive enough attention or to achieve the anticipated penetration rates. The penetration rates of advanced energy-efficiency technologies are still plagued by the obstacles of systems and mechanisms, in addition to asymmetric informa-

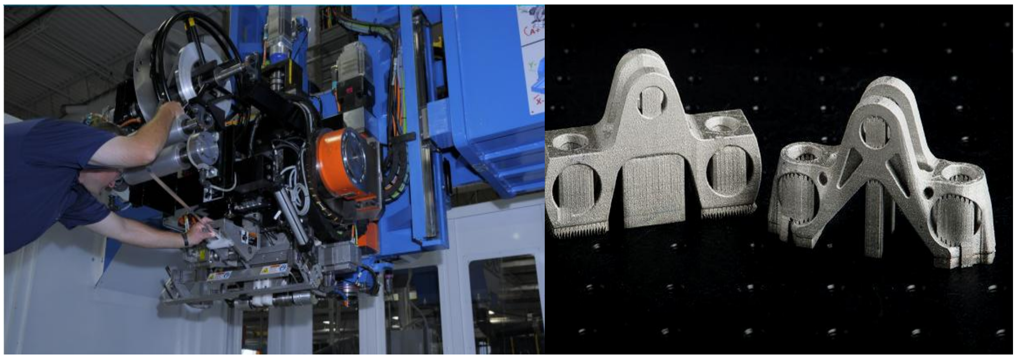
BOX 1. Material additive manufacturing: 3D printing technology

Introduction

Topic: energy demand reduction through material efficiency improvement
Company: General Electric (GE Aviation and GE Healthcare)
Region: United States
Sector: manufacturing
Year: 2014

Summary.
3D printing or additive manufacturing is the manufacturing of an object by adding ultrathin layers of materials. Currently it is in the transition stage, moving from rapid prototyping to high-value manufacturing. In particular, the aerospace and medical implants industries have shown strong growth in adopting 3D printing technologies. .

General Electric (GE) has established a full-scale additive manufacturing facility in Cincinnati, Ohio, United States. Overall, more than 300 3D printing machines have been deployed in GE's facilities. GE Aviation is exploring the use of 3D printing on titanium, aluminum, and nickel-chromium alloys. It plans to use 3D-printed fuel nozzles on its newest aircraft engine (the CFM LEAP engine) by 2016. By 2020, GE Aviation is expected to manufacture 100,000 additive parts through 3D printing. In addition, GE Healthcare is manufacturing 3D-printed ultrasound transducers and probes for use in ultrasound machines.



Left: Loading metal foil to an additive manufacturing welding machine (source: Fabrisonic)
Right: Prototypes of brackets for airplane engines (source: MIT Tech Review)

Benefits

- **Material savings**: -500 kg of potential reduction in weight of a single aircraft engine; possibly up to 90% in reduction of material needs
- **Energy savings:** 75-98% energy savings
- **Co-Benefits:** reduced time in manufacturing and increased flexibility

Challenges

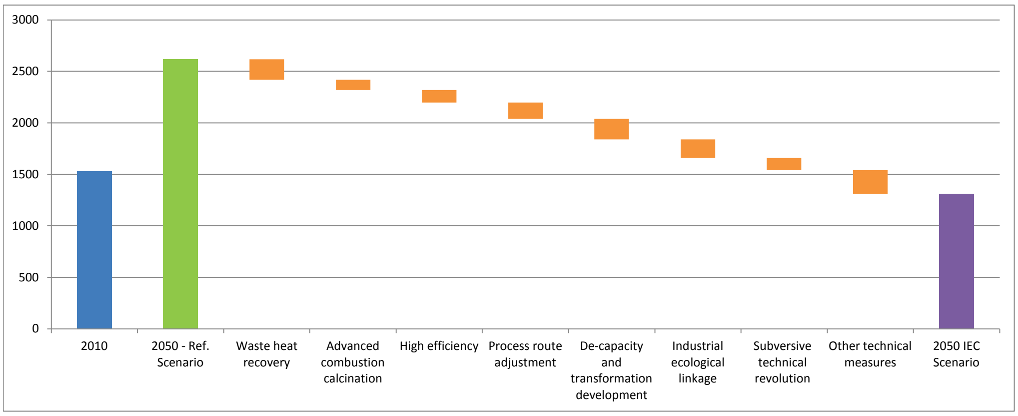
- Achieving cost-effectiveness and economies of scale.
- Ensure product resilience
- Meet quality and safety standards
- Protect intellectual property rights

tion, high technical thresholds and the reluctance among enterprises to accept new technologies. Therefore, addressing such problems through innovative and market-oriented policy measures is urgently needed.

3.4.1 WIDEN THE CHANNELS FOR ENTERPRISES TO ACQUIRE INFORMATION AND EXAMPLES OF THE APPLICATION OF ENERGY-EFFICIENCY TECHNOLOGIES

With the in-depth promotion of energy efficiency, general energy-efficiency technologies have basically been saturated and the 'low-hanging fruit' are gathered. In the future, enterprises will face increasing difficulties in carrying out energy-efficiency actions, and there will be higher requi-

FIGURE 3-18. Potential assessment of major energy efficiency opportunities by 2050



rements for talent, technologies and information. In recent years, the Chinese government has implemented a series of policy measures to support enterprises in energy efficiency improvement, including publishing a catalogue of energy-efficiency technologies, educating energy management talent for enterprises, implementing energy-efficiency benchmarking actions and promoting energy management systems, which have all played a certain role in promoting energy efficiency in industrial enterprises. However, given the increasing difficulties associated with energy efficiency improvement, the existing policy measures are gradually losing their effects and even becoming disconnected from the demands of enterprises.

Recommendation: improve policies for energy efficiency-related information services. Organize comprehensive assessment on the efficiency and energy-efficiency benchmarking actions, regularly amend and update the catalogue of energy-efficiency technologies, encourage and support enterprises in carrying out energy audits, and actively push forward the evaluation and certification of energy management systems. **Promote energy manager systems.** Mobilize industry associations, colleges, universities and scientific research institutions to train specialized talents for energy management for different industries and at different levels. **Implement energy-efficiency top-runner actions and define best energy-efficiency practices.** Regularly choose the best enterprise in terms of energy efficiency from the major products and energy-intensive industries as the top runner, and set up a long-term mechanism for improving energy efficiency by establishing benchmarks for energy efficiency improvement, complete compliance measures and improving energy-efficiency standards. **Encourage the relevant parties to establish energy-efficiency credit-evaluation systems, energy-efficiency cooperation networks and information exchange platform.** Create platforms for 'public comments' and 'Alipay' to establish market-oriented evaluation systems for energy-efficiency equipment manufacturers, energy-efficiency service companies, energy-using enterprises and relevant market service agencies, perfect the energy-efficiency information exchange mechanism, and regularly publish information on the applications of advanced energy-efficiency technologies both abroad and at home among enterprises engaged in similar business activities or of the same industry.

3.4.2 COMPLETE THE ENERGY-EFFICIENCY STANDARD SYSTEM RELATED TO PRODUCTION PROCESSES, TECHNOLOGIES AND EQUIPMENT

After over ten years of efforts in energy-efficiency improvement, China's industrial energy efficiency has been substantially improved, but the potential tapping also creates pressures and challenges to the continuous development of energy efficiency in the future. With the high penetration of routine energy-efficiency technologies and equipment, the energy-efficiency programs of enterprises have gradually stepped into a 'deep water area'. Advanced production processes, efficient technologies and equipment generally involve higher application thresholds and major uncertainties. In addition, enterprises have lowered their ambitions to achieve further energy efficiencies due to the falls in energy prices and difficult market situations the 'new normal' of economic circumstances. Therefore, in addition to promote energy efficiency through information publicity and introduction of examples, it is also necessary to adopt a standard mode to encourage, guide and force enterprises to introduce advanced and efficient production processes, technologies and equipment.

Suggestion: Assess the actual progress made by industries and enterprises in energy efficiency improvement and timely update and revise the energy-efficiency standards for energy-intensive products. Properly improve the minimum requirements for energy-efficiency standards,

raise the energy efficiency threshold for new energy-intensive projects to ensure energy efficiency, environmental protection and safety. In accordance with the physical conditions of industrial energy efficiency, improve the advanced value of energy-efficiency minimum standards and use them as an important basis for selecting the 'top runner of energy efficiency' and demonstration enterprises for energy efficiency. **Gradually improve the standards for the construction and design of enterprises in energy-intensive industries.** In accordance with the production characteristics of different industries, study the application domains, range of advanced production processes and high-efficiency environmentally friendly equipment. In combination with actual cases, gradually incorporate them into the standard system of factory design. **Normalize the market order and complete the technical standards for the production of energy efficiency equipment.** For innovative and disruptive technical equipment, technical standards should be adopted to ensure the 'lower limits' of its energy efficiency, quality and security.

3.4.3 REMOVE THE SYSTEM AND MECHANISM BARRIERS ACROSS DEPARTMENTS AND INDUSTRIES

The experiences of developed countries indicate that future industrial enterprises will not only act as the manufacturers of industrial products but also as composite and socialized enterprises. Taking into account the social benefits of industrial enterprises is not only an important aspect of achieving energy efficiency in the whole of society, it also provides another 'rich ore' for Chinese energy efficiency in the future. However, being restricted by the existing fragmented administration system, many energy-efficiency measures across departments, industries and even enterprises are proving difficult to implement.

Suggestion: strengthen organizational leadership and establish coordination mechanisms across departments and industries. China should further establish the system for the recovery of waste resources, establish leadership and coordination mechanisms, make clear who the specialized agencies and staff are, establish the departmental coordination mechanism, and make clear responsibilities in creating joint workforces. **Establish and perfect the relevant standard system for the development of venous industries.** Speed up the establishment of relevant standards for the recovery of industrial wastes, reclamation of wastes and pollutant emissions, and perfect the product standards for energy efficiency, water conservation and the comprehensive utilization of resources. **Establish a consulting service system to strengthen technical instructions regarding the cyclic utilization of resources and energy.** Mobilize experts in the relevant fields from industry associations, colleges, universities and scientific research institutions to make and draw up comprehensive evaluations, instructions, training regimes and consultations for major allocations of productive forces, the design of industrial parks and actual production links between enterprises. **Complete the construction of infrastructural facilities that are favorable to the optimal utilization of resources and energy.** Devote more efforts to the construction of logistical transportation pipe networks related to the recovery of wastes and the cascaded utilization of energy.

3.4.4 ESTABLISH AN INSTITUTIONAL ENVIRONMENT FAVORABLE TO THE OPTIMIZATION AND UPGRADING OF INDUSTRIAL STRUCTURES AND THE IMPROVEMENT OF INDUSTRIAL COMPETITIVENESS

Optimizing and upgrading the industrial structure and rebuild competitive industrial advantages are fundamental ways of improving the energy production capacity of industrial sectors and are of great significance in making improvements to the energy efficiency of industrial sectors. In addition, and in response to the rises in labor costs and resource and environmental costs, as well as increases in international competition, these two measures are inevitable candidates for readjustment to the industrialization mode. This is a major proposal relating to whether China can carve out a new road to industrialization by taking into account speed, quality, scale and benefits.

Suggestion: establish market-oriented pricing mechanisms for production factors in order to guide energy-intensive industries to 'de-capacity' in a market-based way. Gradually remove the administrative measures whereby the government intervenes directly or indirectly in the configuration of factors of production such as land and energy resources, allow the relationship between market supply and demand and the competitive mechanism to determine the prices of factors of production, and in turn eliminate backward capacities. **Reduce unnecessary government regulations, carry out 'negative list' management, and exploit the investment channels for social capital.** Adopt public-private partnerships to guide social capital to enter the fields of public services and infrastructure construction, and guide social capital to enter such fields as finance, insurance, medical treatment and education. **Encourage R&D and the protection of intellectual property.** Support the construction of a foundational scientific research capacity, continue to carry out key scientific and technological projects, establish an integrated platform for 'researching-learning-producing', and strengthen the protection of intellectual property. **Integrate the application of such measures as fiscal subsidies, tax preferences and financing guaranties to support**

the development of tertiary industries, in particular the productive service industry.

REFERENCES

China Iron and Steel Association, 2015. Research on the control of total coal consumption in steel industry.

Chinese Academy of Sciences, 2012. Special research on the causes and control measures for atmospheric haze[M]. 2012.

CNIS (China National Institute of Standardization) 2015. White Paper for the Energy Efficiency of China 2014 [M]. 2015.

Fan Wei. Development status of industrial pulverized coal boiler industry as well as investment analysis [J]. Clean coal technology. 2012,18(4).

Liang Xing, Yan Lili and Xu Yao. Analysis on the status and development direction of coal water slurry technology [J]. Clean coal technology. 2012 volume 18, issue 6.

Liu Xiwu. Coal water slurry fired boiler application technology and its market outlook [J]. Construction technology 2014 volume 4, issue 16

Yi Wei, Lang Dongfeng and Wang Jianwei. Prospect of coal water slurry fired boilers [J]. Gansu Water Resources and Hydropower Technology. 2012 volume 48, issue 8.

CHAPTER 4

ENERGY EFFICIENCY POLICY AND THE HIGH IMPACT OPPORTUNITIES OF THE BUILDING SECTOR IN CHINA

Jianguo ZHANG

4.1 REVIEW OF ACHIEVEMENTS AND POLICIES REGARDING ENERGY EFFICIENCY IMPROVEMENTS IN THE CHINESE BUILDING SECTOR

4.1.1 ENERGY EFFICIENCY IMPROVEMENTS IN THE BUILDING SECTOR

The building sector is an important energy-consuming sector in China. In 2013, total energy consumption in the sector (i.e. commercial energy, exclude biomass energy) was recorded as 756 Mtce, accounting for about 20% of total national energy consumption. During 2000-2013, total energy consumption increased by 2.2 times, indicating a high growth rate. Meanwhile, the floor area of buildings is huge and continues rapid growth. In 2013, the national stock of buildings recorded a floor area of about 54.5 billion square meters, with floor area of urban residences, rural residences and public buildings of 20.5 billion square meters, 23.8 billion square meters and 9.9 billion square meters respectively; the floor area of buildings is growing at an annual speed of nearly 2 billion square meters (THUBERC 2015). However, the energy efficiency of the Chinese building sector as a whole is relatively low. Among the urban buildings, only one third are energy-efficient ones. In addition, requirements in China's existing standards for energy-efficient buildings are only equivalent to the standards in European countries twenty years ago. On the other hand, due to relatively low energy service levels, the energy consumption per capita and the energy consumption intensity per square meter of floor area in the building sector are much lower than the those of the developed countries.

The energy-efficiency initiative for buildings began in the late 1980s in China, while the overall strategy for energy efficiency in buildings have been gradually implemented, with the priorities starting with the easier items, then the more difficult items, first urban areas, then rural areas, first new buildings, then existing buildings, first residential buildings, then public buildings, and first in the north of the country (cold and severe cold regions) and then to the south. Through over thirty years of efforts, China has conducted a series of programs to improve the building design standards, laws and regulations, as well as the organization and administrative systems for energy efficiency in buildings. Compulsory energy efficiency standards have been established for new buildings, government incentives are provided to carry out energy conservation retrofits to existing buildings. Various measures are put in place to encourage the large-scale application of renewable energy sources based on buildings, the development of green buildings, and the penetration of high-efficiency electrical appliances, all of which have achieved remarkable results.

During the 12th FYP period (2011 - 2015), China launched a nationwide *Green Building Action Programme* to open a new era in the development of energy efficient buildings and green buildings. To further improve the energy efficiency level of new buildings, higher energy-efficiency design standards for buildings have been implemented in an all-round manner for new urban buildings in all parts of the country. Great efforts have been devoted to the development of green buildings, so that the total floor area of buildings with a green building label in the whole country had reached 415 million square meters as of August 2015. China has also developed eight country-level green ecological urban areas. If the green buildings in these green ecological urban areas are taken into count, more than 22.34% of new urban buildings had met the requirements of the green building standard by the end of 2015 (Han et al 2013). China has completed heat metering and energy conservation retrofits to approximately 960 million square meters of existing residential buildings in North China where district space heating is compulsory in urban areas. It has also rolled out the energy efficiency supervision system for government office buildings and large-scale public buildings, as well as energy conservation retrofits to public buildings with high energy consumption. Twelve demonstration projects for energy conservation retrofits to public buildings have been implemented in major cities, with a total floor area of 44.41 million square meters. Moreover, the government has launched the large-scale application of renewable energy based on buildings, and nominated 97 demonstration cities and 198 demonstration counties for the application of renewable energy based on buildings. In combination with rehabilitation of dilapidated housing in rural areas, China has also carried out pilot demonstration projects for energy efficiency in buildings in rural areas, established 842 demonstration pilot counties (county-level cities and districts) for energy efficiency improvement among rural housing, and nominated 825,800 rural households as energy-efficient residences (MOHURD 2015).

Almost 100% of the new urban buildings throughout the country conform to the compulsory energy-efficiency standards. During the 12th FYP period (2011-2015), the residential buildings in the north have generally followed the standard of 'energy saving by 65%' (*Design Standard for Energy Efficiency of Residential Buildings in Severe Cold and Cold Zones*, JGJ26-2010), while some regions like Beijing, Tianjin, Tangshan in Hebei Province and Urumqi in Xinjiang have started to implement a compulsory standard for 'energy saving by 75%'. For residential buildings in the hot summer and cold winter zones or the hot summer and warm winter zones, the revised standard 'energy sa-

ving by 50%' has been implemented, and for public buildings, the standard is 'energy saving by 50%'. However, since October 1, 2015, the newly revised *Design Standard for Energy Efficiency of Public Buildings* has been implemented in an all-round manner, to improve the energy efficiency of new buildings. By the end of 2014, in the design and construction phases of new buildings in urban areas, the implementation rates of the compulsory energy-efficiency standards reached 100% and 98.98% respectively. In the super-large cities, the proportion reached 100%. China has completed 1,017 demonstration buildings featuring low or ultralow energy consumption (MOHURD, 2015). In the first four years during the 12th FYP period, the total floor area of new energy-efficient buildings in urban areas is expected to exceed five billion square meters, meaning that the accumulated area of energy-efficient buildings in urban areas would exceed ten billion square meters, accounting for approximately a third of the stock of urban buildings.

Green buildings are being developed rapidly. Since the General Office of the State Council issued the *Green Building Action Programme* in January 2013, 28 provinces and cities in China have issued their on schemes for Green Building Action in accordance with local circumstances to make clear the development objective, key tasks and major measures for local green buildings, and 22 provinces (autonomous regions and/or municipalities directly under the central authority) have published their own local evaluation criteria for green buildings. Since 2014, the national requirements for public buildings such as government office buildings, schools and hospitals have to take the lead in meeting the standards for green buildings. As of August 2015, a total of 3,605 projects have been awarded the green building label, with gross building area up to 415 million square meters, in which there are 3,407 projects with a green building design label, 198 projects with a green building operation label, 1,469 one-star projects, 1,484 two-star projects, 652 three-star projects. The labels cover 1,745 residential buildings, 1,833 public buildings and 27 industrial buildings. In 2014 alone, 780 projects were awarded a green building evaluated label, with a total building area of up to 8,762 square meters (MOHURD 2015). At present, except in Tibet, projects with green building labels can be found in all provinces (autonomous regions and municipalities directly under the central government administration) and all the prefecture-level cities under the administration of Beijing, Shanghai, Tianjin, Chongqing, Jiangsu, Shannxi, Hebei, Zhejiang and Shanxi. In all the prefecture-level cities under the administration of Shandong, Henan, Fujian, Anhui, Inner Mongolia, Jilin and Guangdong, over 50% of the projects are labeled as green buildings.

China exceeded its targets for conducting energy conservation retrofits to existing residential buildings during the 12th FYP period. With an emphasis on the building envelope improvement, heat supply metering and heat balance transformation to pipeline networks, northern China has actively implemented a project called *Energy Conservation and Warm House*. During 2011-2014, China completed heating supply metering and energy conservation retrofits to residential buildings with an accumulated building area of 960 million square meters, thus more than fulfilling the objective of 400 million square meters set by the State Council. Heat supply metering has been also promoted in a comprehensive manner. At present, in the north, 116 cities at the prefecture level or above have introduced metering-based heat pricing and charging mechanisms, accounting for 93% of cities at the prefecture level or above in this region. By the end of 2013, China had increased its floor areas subjected to heat metering to 991 million square meters (MOHURD 2015). With windows and doors, external shading and natural ventilation as priorities, China has carried out pilot projects for energy conservation retrofits to the residential buildings in the hot-summer-and-cold-winter regions, as well as regions of hot summer and warm winter. By the end of 2013, retrofit project with a total floor area of up to 11.75 million square meters had been completed in these regions (MOHURD 2014).

Promote the development of green housing in rural areas. During the 12th FYP period, governments at all levels have actively carried out pilot projects on energy conservation retrofits to dilapidated rural housing and promoted the prefabrication of energy-efficiency buildings in rural areas, thus making new progress in energy efficiency improvement of rural buildings. By the end of 2014, fifteen provinces (autonomous regions and municipalities directly under central government administration), including Heilongjiang, Jilin and Liaoning, have carried out demonstration projects of energy efficient buildings in combination with the rehabilitation of dilapidated rural housing, nominated 842 demonstration pilot counties (county-level cities and districts), for building energy conservation retrofits to rural housing and supported 825,800 farmer households as energy efficiency demonstration projects (MOHURD 2015). In the demonstration projects of energy efficiency for rural housing, fabricated buildings, the integration of thermal insulation with building structure, the fabricated energy-efficient houses with compound walls in lightweight steel structures and the structure system of a wall body with EPS cavity modules have been introduced in batches. Local governments have started to identify typical technological packages for energy conservation retrofit to rural housing, thus promoting the development of emerging enterprises to supply rural energy efficiency materials, energy-efficient products and fabricated buildings. At present, more than thirty manufacturers are specialized in improving the energy efficiency of rural housing throughout the country.

China has developed a supervisory and administrative system for the energy efficiency of public buildings, actively carried out energy conservation retrofits to large public buildings, and started pilot projects for energy-efficient campuses. During the 12th FYP period, all provinces and cities have collected data on the energy consumption, energy audits, published information on public buildings' energy performance. The governments calculated the energy consumption for 213,073 public buildings, performed energy audits for 12,976 public buildings, published data on the energy performance for 13,656 buildings, and conducted continuous monitoring of energy consumption for 7410 buildings (MOHURD 2015). In addition, 33 provinces and cities have established energy-efficiency monitoring platforms for public buildings. Seven provincial level platforms, including those in Beijing, Chongqing and Shandong, have been built and passed inspection. China has actively carried out energy conservation retrofits to large-scale public buildings, focusing on such key components of energy conservation retrofits as heating, air-conditioning, ventilation and lighting,. Through such measures as fiscal subsidies, tax preferences and incentive policies for contracted energy management project, the central government has encouraged energy conservation retrofits to be made to public buildings, and local governments have also launched similar incentive policies to support such retrofits. Twelve cities, including Tianjin, Chongqing, Shanghai, Shenzhen, Qingdao, Jinan, Fuzhou, Xiamen and Xining, have been listed as key candidates for energy conservation retrofits to public buildings. China also has started pilot projects to create energy-efficient campuses in more than two hundred colleges and universities. At present, demonstration projects for energy efficiency supervision systems in buildings have been launched in 256 colleges and universities throughout the country, and projects from nearly a hundred colleges and universities have passed acceptance, resulting a 13% saving in electricity consumption and 12% saving in water consumption on average; the savings in energy resource expenditure per school is US$ 476,000 or RMB 3 million (MOHURD 2015). the experiences of colleges and universities in energy efficiency are gradually replicated in other public agencies. At present, 44 hospitals affiliated to various ministries have implemented pilot energy efficiency projects to build themselves into energy-efficient hospitals, and nineteen scientific research institutes have participated in the program for creating energy-efficient institutes. Some state administrative departments have also launched campaigns for creating energy-efficient offices and carried out comprehensive energy conservation retrofits to their office buildings, achieving remarkable effects in energy conservation and emissions reductions, as well as economic benefits.

China has also carried out large-scale development of renewable energy in buildings. During the 12th FYP period, by following a strategy of ‘project demonstration, regional demonstration and all-round promotion’, China actively promoted the introduction of renewable energy in buildings. Supported by regional demonstrations, this policy has gradually produced scale benefits, and significant progress has been made in improving technologies, policies, labor skills and standards. During the 12th FYP period, China also implemented 398 demonstration projects for the introduction of solar PV on buildings, 25 provincial-level projects to promote the introduction of renewable energy in buildings, 97 demonstration cities, 198 demonstration counties, 6 demonstration districts, 16 demonstration towns and 21 technical R&D and industrialization projects. Eight provinces (regions), including Jiangsu, Ningxia, Qinghai and Xinjiang, were identified as comprehensive demonstration zones for the introduction of solar PV on buildings. As of the end of June 2014, the total area of solar PV installed in buildings in urban regions had reached 2.7 billion square meters, the total floor area of buildings equipped with shallow-layer geothermal energy had reached 400 million square meters, and the installed capacity of solar PV among the completed buildings and those under construction had reached 1875 MW (MOHURD 2015). As compared with the levels recorded in 2010, these figures increased respectively by 1.22 billion square meters, 173 million square meters and 1024.4 MW, indicating rapid growth in all three aspects.

The energy efficiency of public institutions also has been improved. In the whole country, China has preliminarily established an administration system, a legal and regulatory system, a meter-monitoring and inspection system, a technical support system, an awareness-raising and training system, and a market-oriented service system for energy efficiency improvement in public institutions. Energy conservation retrofits to the office buildings of public institutions and demonstrations of energy efficiency in public institutions have been carried out. In the first four years of the 12th FYP period, the state agencies completed heat metering and energy conservation retrofits to office buildings with a total area of 2.52 million square meters, while various provinces (regions and municipalities) carried out energy conservation retrofits to 82 million square meters of office buildings of public institutions, and implemented energy conservation retrofits to 170,000 square meters of data center buildings (NGOA 2015). The per capita energy consumption and energy consumption per square meter of public institution buildings have steadily declined. In the first four years of the 12th FYP period, energy consumption per unit building area of public institutions dropped by 11.05% nationwide and reached a record low value of 21.22 kgce/m² in 2014. The total energy consumption per capita decreased by 13.92% and reached a record low of 385.11 kgce/person in 2014 (NGOA 2015).

4.1.2 REVIEW OF THE MAIN POLICIES PROMOTING ENERGY EFFICIENCY IN BUILDINGS

Strengthen the planning guidance for energy efficiency in buildings

During the 12th FYP period, the Chinese government issued a series of policies, made plans, specified the government agencies and entities responsible implementing the plans and target tasks, and strengthened the assessment and inspection of progress with plan implementation, thus effectively guiding the nationwide work of improving the energy efficiency of buildings and building green buildings. During the 12th FYP period, the State Council issued a series of policy documents (see Table 4-1), including the overarch plan for energy conservation and emission reductions and other specific plans to support the realization of the overarch plan. Among them, the *12th FYP for Building Energy Efficiency Improvement* and the *Green Building Action Program* are major policy documents providing specific guidance for working on energy efficiency in buildings during the 12th FYP period.

The 12th FYP for Building Energy Efficiency Improvement set out an overall target of achieving 116 Mtce of energy efficiency improvement in buildings by the end of the 12th fYP period. This includes a target of achieving 45 Mtce of energy efficiency improvement through the development of green buildings and energy efficiency improvement of new buildings. Another specific target is to speed up the reform of the heating supply system, to comprehensively carry out metered heat-supply charging and promote the heats metering and energy conservation retrofit to the existing buildings in the northern heating regions, so as to achieve energy efficiency of up to 27 Mtce. Another action area is to strengthen the energy efficiency supervision system for public buildings and push forward the management of energy conservation retrofits and operations, so as to achieve 14 Mtce of energy saving. The final action area is to promote the integrated application of renewable energy in buildings, so as to substitute 30 Mtce of traditional fossil fuel use.

The *Green Building Action Program* provided a framework plan for actions to improve energy efficiency in buildings

TABLE 4-1. Policy documents related to building energy efficiency improvement during the 12th Five-year period

POLICIES	ISSUED BY	ISSUED
The 12th FYP for Energy Conservation and Emission Reductions	The State Council	Aug., 2012
The Comprehensive Work Plan for Energy Conservation and Emission Reductions during the 12th FYP Period	The State Council	Aug., 2011
Green Building Action Program	General Office of the State Council	Jan., 2013
National Plan for New Urbanization (2014 - 2020)	The Central Committee of the Communist Party in China, The State Council	March, 2014
The 12th Five-year Development Plan for Energy Efficiency and Environmental Protection Industry	The State Council	June,2012
The 12th Five-year Development Plan for National Strategic Emerging Industries	The State Council	July, 2012
The Strategic Action Plan for Energy Development (2014-2020)	The State Council	Nov., 2014
National Plan for Addressing Climate Change (2014- 2020)	The State Council	Sept., 2014
Action Program for Energy Conservation, Emission Reduction and Low-carbon Development during 2014-2015	General Office of the State Council	May, 2014
The 12th FYP for Building Energy Efficiency Improvement	MOHURD	May, 2012
The 12th Five-year Development Plan for Green Buildings and Green Ecological Urban Areas	MOHURD	April, 2013
Outlines of the 12th FYP for Urban Green Lighting	MOHURD	Nov., 2011
The 12th FYP for Energy Efficiency Improvement in Public Institutions	National Government Offices Administration.	Aug., 2011
Action Program for Promoting the Production and Application of Green Building Materials	Ministry of Industry and Information Technology, Ministry of Housing and Urban-Rural Development	Aug., 2015
Specialized Action Program of Promoting the Science and Technology for Energy Conservation and Emission Reductions during 2014-2015	Ministry of Science and Technology, Ministry of Industry and Information Technology	March, 2014

and to develop green buildings during the 12th FYP period and it specified the goals, tasks and measures, and required that all new buildings should be designed and built in strict compliance with the compulsory energy-efficiency standards. The Program's target is to complete new green buildings of up to a billion square meters during the 12th FYP period. By the end of 2015, 20% of new buildings in urban regions should meet the requirements of the standards for green buildings. In the meanwhile, this action program requested that government agencies at all levels to effectively introduce energy efficiency in new buildings, devote great efforts to carry out energy conservation retrofits to existing buildings, carry out retrofits to the heating systems in urban areas, push forward the large-scale application of renewable energy in buildings, strengthen the energy efficiency management of public buildings, speed up research, development and promotion in relation to green building-relevant technologies, energetically develop green building materials, push forward prefabricated buildings, strictly observe the management procedures for demolishing buildings, and promote ten key tasks, including the conversion of building wastes into resources, as well as relevant supporting measures.

Perfect the energy efficiency standards system for buildings

Since the beginning of the 12th FYP period, the Chinese government has issued and implemented multiple standards for energy efficiency in buildings and for the evaluations of green buildings, as shown in Table 4-2.

In addition, relevant sectors have also prepared the *Green Assessment Standard for Transformation to the Existing Buildings*, *Assessment Standard for Green Eco-district* and *Technical Specification for the Operation and Maintenance of Green Building*. In particular, a comprehensive update has been made to the *Design Standard for Energy Efficiency of Public Buildings*, so as to raise the compulsory standards for the insulation performance of building enclosures, as well as the cold/heating equipment and system.

So far, China has established a national standard system for energy efficiency in buildings which covers different climatic zones, different building types and different energy categories, and has preliminarily established a technical standard system for green buildings, ranging from a one-star level to a three-star level. In addition, more than twenty provinces all over the country have established more than a hundred local standards for building energy efficiency in accordance with their local conditions. For example, Beijing and Tianjin have established and implemented a standard of 'energy saving by 75%' for new buildings; Hebei and Heilongjiang have issued standard specifications for the design and evaluation of green buildings with ultra-low energy consumption; and Hebei Province has issued a *Standard for Energy Efficiency of Passive Low Energy Consumption Residential Buildings* (taking effect from May 1, 2015), which is not only the first Chinese standard for passive buildings, but also the second such standard in the world after Sweden issued the *Specification for Passive Low Energy Residential Buildings*, creating a new milestone in the Chinese history of passive building development.

TABLE 4-2. Sstandards for energy efficiency in buildings issued during the 12th FYP period

NAME OF STANDARD	NUMBER OF STANDARD	COMING INTO FORCE
Design Standard for Energy Efficiency of Residential Buildings in Hot Summer and Warm Winter Zone	JGJ75-2012	April 1, 2012
Design Standard for Energy Efficiency of Rural Residential Buildings,	GB/T50824-2013	May 1, 2013
Standard for Energy Efficient Building Assessment	GB/T50668-2011	May 1, 2012
Evaluation Standard for Urban Green Lighting Energy Efficiency	JGJ/T307-2013	February 1, 2014
Assessment Standard for Green Buildings	GB/T50378-2014	January 1, 2015
Evaluation Standard for Green Industrial Buildings	GB/T50878-2013	March 1, 2014
Evaluation Standard for Green Office Buildings	GB/T50908-2013	May 1, 2014
Evaluation System for Green Hospital Buildings	CSUS/GBC2-2011	July, 2011
Evaluation System for Green Campus	CSUS/GBC04-2013	April 1, 2013
Code for Green Design of Civil Buildings	JGJ/T229-2010	October 1, 2011
Evaluation Standard for Green Construction of Buildings, Technical Guideline for Green Affordable Housing (Trial)	GB/T50640-2010	October 1, 2011
General Technical Rules for Measurement and Verification of Energy Saving Amount	GB/T28750-2012	January 1, 2013
Design Standard for Energy Efficiency of Public Buildings	GB50189-2015	October 1, 2015

Implement economic incentive policies

Fiscal subsidy. During the 12th FYP period, the central government provided financial subsidies for key cities and higher institutions of learning to introduce energy conservation retrofits to public buildings. The subsidy standard was fixed at 3.2 US$/m² (20 RMB/m²) in principle and took into account such relevant factors as the workload of energy conservation retrofits, their contents and effects. To promote heat metering and energy conservation retrofit projects to existing residential buildings in the northern heating regions, during 2011-2014, the incentives provided by central government remained the same levels as those fixed in 2010, namely 8.7 US$/m² (55 RMB/m²) for severe cold zones and 7.1 US$/m² (45 RMB/m²) for cold regions. After 2014, these standards were lowered moderately in accordance with particular circumstances. According to the *Tentative Measures for the Management of the Financial Incentive Fund for Contract Energy Management* jointly printed and issued by the Ministry of Finance and the NDRC in June 2010, the financial incentive should be provided as a one-off award to the contract energy-management project based on the levels of annual energy saving s and specified standards, with the award funding jointly contributed by the central government and provincial governments. The subsidy from the central government budget is 38 US$/tce (240 RMB/tce), and that from the provincial government budget shoud be at least 9.5 US$/tce (60 RMB/tce). In addition, local governments, where the actual economic conditions allow, were encouraged to raise the incentive standard moderately based on local circumstances. In 2012, the MoF and the MOHURD jointly issued a *Notice on Improving the Policies on the Application of Renewable Energy in Buildings as Well as Regulating the Fund Allocation and Administration*. To support the provincial-level demonstration projects for the introduction of renewable energy in buildings, MoF transferred a partial subsidy fund to provincial finance and the provincial authority on housing and urban-rural development for unified planning and administration coordination. However, since May 2015, the original financial incentives for energy conservation retrofits and contract energy management and the subsidy for energy conservation retrofits to existing buildings in the hot summer and cold winter zones have been abolished.

Tax preferences. The preferential taxation policies for energy efficiency in buildings mainly covers preferential corporate income tax, preferential value-added tax and preferential business tax. The current *Corporate Income Tax Law* provides some preferential policies For enterprises and projects that adopt environmental protection equipment, make comprehensive utilization of resources and engage in projects for environmental protection, energy efficiency and/or water savings. For specific building materials, if the waste residues blended in the raw materials is 30% or above, VAT is exempted. For VAT realized by selling partial new wall building materials, a refunding of 50% of VAT upon collection is offered. For clay solid bricks and/or clay tiles manufactured by a general VAT taxpayer, VAT should be levied according to the applicable tax rate, but the VAT shall not be calculated by using the simple calculation method. For the purposes of selling one's own gravel aggregates combined with building (structure) waste and gangue as raw materials, VAT is exempted, provided the proportion of building (structure) waste and gangue in the raw materials for production may not be less than 90%. The preferential sales tax is mainly applicable to the contract energy management project. In December 2010, the Chinese government issued a *Notice on the Value Added Tax, Business Tax and Corporate Income Tax Policies for Promoting the Development of Energy Efficiency Service Industry*. The Notice stipulated that, if an energy efficiency service company realizes some taxable income from implementing a contract energy management project, it will be temporarily exempted from paying business tax. If an energy efficiency service company meeting the conditions implements a contract energy management project, it may qualify for the arrangement whereby 'corporate income tax on energy efficiency projects is exempted for the first three years and levied at 50% in the next three years'. In 2013, the *Public Notice on Collection Management Issues Relating to Preferential Corporate Income Tax Policies on Contract Energy Management Projects Implemented by Energy Efficiency Service Enterprises* was issued to further improve the operability of preferential tax policies on contract energy management.

Preferential financial policy. In 2012, the China Banking Regulatory Commission (CBRC) issued the *Guidelines for Green Credit* to supervise and urge banks and financial institutions to give more loans to such green projects as energy conservation and emissions reductions from the strategic perspective. In 2013, CBRC released the *Opinions on Green Credit Work* to further promote the development of green credit. CBRC took the lead in establishing a statistical system for green credit to include projects for energy efficiency improvement in buildings and green building development in the twelve categories of energy efficiency and environmental protection projects and services, thus improving the examination and evaluation system for green credit. In the *Guidelines for Energy Efficiency Credit (Revised)*', CBRC clearly listed energy efficiency improvement in buildings as a key field to be supported by energy efficiency credits and requested banks and financial institutions to give more credit aid to green building projects that comply with the *Green Building Action Program*.

Pricing policy. In 2011, China started to pilot a tiered pricing policy for residential electricity, divided the monthly electricity consumption of households into

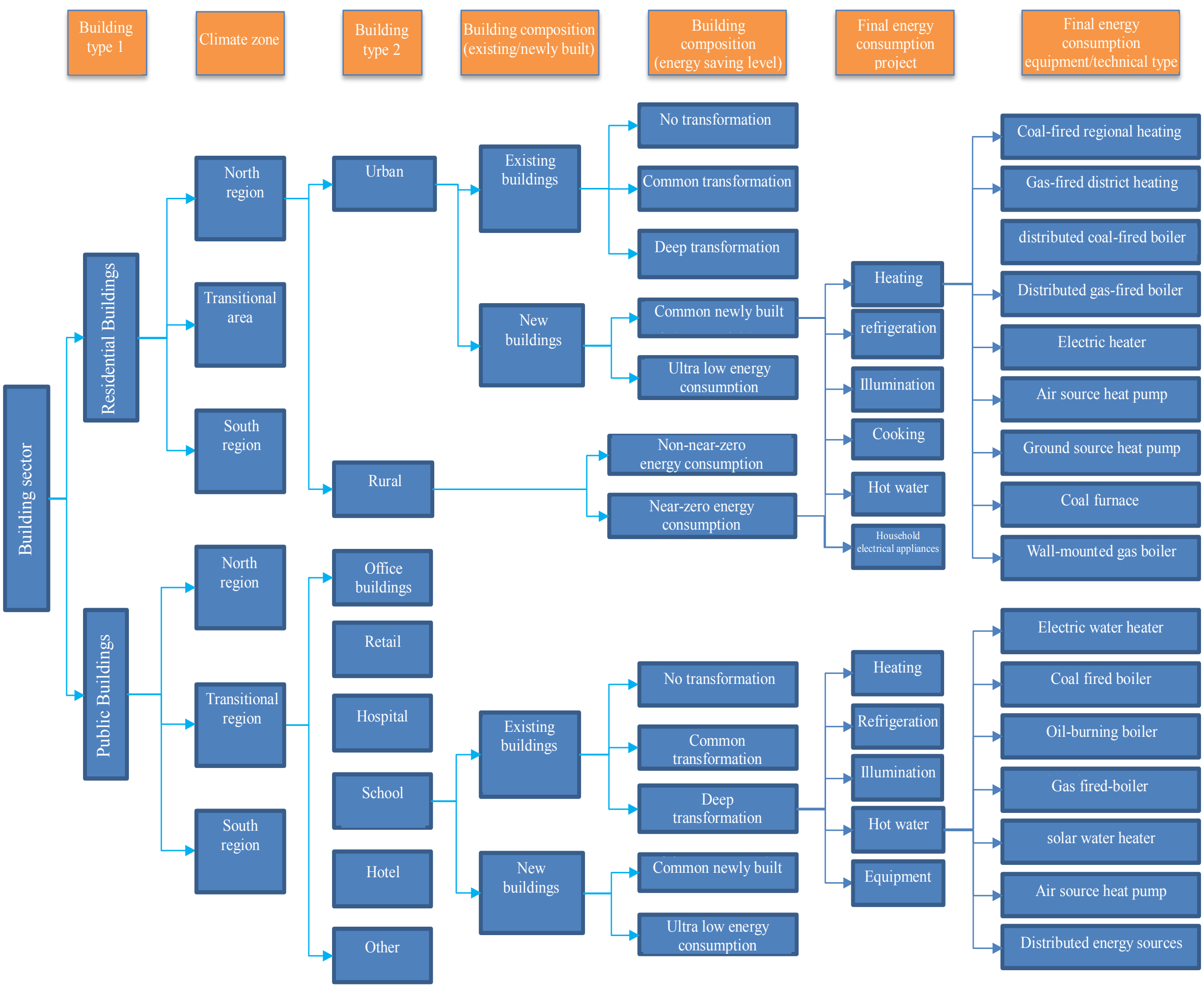
three levels, increased the free level for low-income families, and started to charge higher rates for residential power consumption exceeding local standards to discourage wasteful use and ensure meeting a basic demand for power consumption by households. In 2013, the Chinese government also issued a *Notice on Improving the Tiered Pricing System for Household Electricity Use*, requesting the all-round promotion of a peak-valley electricity pricing system for residential electricity consumption. All regions were required to set up and start to implement peak-valley electricity pricing system for residential electricity consumption latest by the end of 2015 and the electricity prices shall be differentiated for households with levels of electricity consumptions. In regions where such systems have been introduced, the system had to be regulated and perfected in a timely manner in accordance with the implementation conditions and the changes in the electric power load.

4.2 PROSPECTS FOR ENERGY CONSUMPTION IN THE BUILDING SECTOR

4.2.1 METHODOLOGY

In this study on the energy consumptions of the building sector, the focus is on urban residential buildings, rural residential buildings and public buildings. The research team adopts the Scenario approach to identify the factors driving changes to the energy consumption of buildings and to project changes in the energy consumption of the building sector in the future. In the process of scenario analysis, the team combines qualitative analysis and quantitative analysis, top-down and bottom-up approaches, and domestic and international comparison, to conduct research into the energy consumption of the building sectors in different climatic zones and with different building types.

FIGURE 4-1. Structural diagram of the building energy demand module of LEAP model



The process includes two stages, scenario setting and scenario calculation. At the scenario-setting stage, in light of the current economic and social situation in China and the development trend in the future in combination with expert predictions of future industrial developments, the team first made some assumptions on future macroeconomic parameters, including GDP, population, urbanization rates and building area per capita etc. on the amount of building activity. Secondly, the team made some estimates on the changes to load intensity, technical equipment efficiency and technical proportions regarding the intensity of building activity. Different activity and activity intensity levels result in different energy consumption projections. It is crucial to make reasonable judgments on the activity amount and activity intensity. In general, comprehensive assessment must be made regarding historical data, development trends, and international comparisons and based on the expert judgement. In the scenario calculation, models and tools of quantitative analysis are used to input the parameters for scenario setting, and the parameters in the base year are checked according to the energy balance sheet. Model calculations can only be made upon the completion of checks, followed by analysis of the results. Meanwhile, if needed, it is feasible to adjust the input parameters to analyze and compare the influences of different factors on the results.

In this research, the energy demand analysis module of the LEAP model is used for quantitative analysis. The LEAP model is an energy-environment model developed by the Boston/Dallas branch of the Stockholm Environment Research Institute (SEI). Over the past three decades, more than 1000 organizations from more than 190 countries have adopted the LEAP model to carry out national and/or regional energy strategy research projects and evaluation research on GHG emissions reductions.

Ranging from building types to types of final energy consumption equipment and technologies, the structure of the LEAP model is divided into six layers. By calculating layer upon layer, accumulation and addition, the total energy consumption of the building sector can be obtained, as shown in Figure 4-1.

In this model, civilian buildings all over the country are first divided into two major categories, namely residential buildings and public buildings. Based on their climate conditions, the country is divided into the northern region, the transitional region and the southern region. The northern region includes the cold area and the severe cold area in the thermal design construction zone and covers Beijing, Tianjin, Hebei, Shanxi, Inner Mongolia, Shandong, Henan, Liaoning, Jilin, Heilongjiang, Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang and Tibet. The transitional area comprises the hot summer and cold winter zones and moderate climate zone and consists of Shanghai, Jiangsu, Zhejiang, Anhui, Jiangxi, Hubei, Hunan, Chongqing, Sichuan, Guizhou and Yunnan. The southern region is the hot summer and warm winter zones, including Fujian, Guangdong, Guangxi and Hainan.

In calculating the energy consumption of residential buildings, given the differences between rural residential buildings and urban residential buildings in their energy consumption characteristics, the relevant values are separately calculated and then added up to arrive at the total energy consumption of residential buildings. In calculating the energy consumption of public buildings, the public buildings are divided into office buildings, stores, hospitals, schools, hotels and other types. Both residential buildings and public buildings are then further divided into existing buildings and new buildings. In this model, the existing buildings are those built before and in 2010, while new buildings are those built after 2010. The existing buildings are further divided into three types, namely non-transformed buildings, the present efficiency buildings (meeting the requirements of the current design standard for the energy efficiency of buildings), and the best possible efficiency buildings (in-depth transformed building, technically feasible but not always economically feasible). They differ in energy demand load densities and the non-transformed buildings have the highest energy intensity. The new buildings are further divided into the present efficiency buildings (meeting the requirements of the current design standard for the energy efficiency of buildings) and buildings with ultralow energy consumption (building with technically realizable ultralow energy consumption), which are different in energy demand load intensities, that of the present efficiency buildings higher than that of buildings with ultralow energy consumption. The rural buildings only include two types, namely existing rural residential buildings and buildings with near-zero energy consumption. For the sake of simplicity, under the Reference scenario (the benchmark scenario) the existing buildings are divided into two types, namely non-transformed buildings and the present efficiency transformed buildings. The new buildings only refer to the present efficiency buildings, namely the new buildings that meet the present design standard for the energy efficiency of buildings. The rural buildings only include the existing rural residential buildings. The other building types are only applied under the selected scenario when the in-depth transformation to the existing buildings, the ultralow energy consumption or near-zero energy consumption of new buildings is taken into consideration.

In this model, the final energy uses of urban-rural residential buildings are divided into six categories, namely heating, cooling, lighting, cooking, domestic hot water and household electrical appliances. The final energy consumption of public buildings is divided into five ca-

tegories, namely heating, cooling, domestic hot water, lighting and equipment. Diversified forms of energy supply (or energy consumption equipment) may be adopted to meet the same building energy service demand. However, different energy supply may have different fuel types and energy efficiency levels, resulting in different energy consumption levels, which should be distinguished.

The final energy demand of the building sector is calculated based on the following equation. The building floor area, the final available figure for energy consumption intensity, the technical proportion and the figure for equipment efficiency are the major input parameters for this model. Through calculation and accumulation layer by layer, this model can finally work out the total energy demand of the building sector.

$$ECB = \sum_n \left\{ ACB_n \times \sum_q \left[P_{q,n} \times \left(\sum_k Intensity_{q,n} \times Share_{k,q,n} / Efficiency_{k,q,n} \right) \right] \right\}$$

Wherein:

ECB - The energy consumption of the building sector

k - The energy /technical category

q - The type of final energy consumption

n - Building type

ACB_n --The building area of building type *n*

$P_{q,n}$ -- The coverage and application extents of final use q in building type *n*

$Intensity_{q,n}$--The available energy intensity of final use q in building type *n*

$Share_{k,q,n}$ -- The proportion of the applications of energy consumption equipment/technology *k* in final energy consumption item q in building type *n*

$Efficiency_{k,q,n}$ -- the energy consumption efficiency of energy consumption equipment/technology *k* in final energy consumption item *q* in building type *n*

4.2.2 KEY ASSUMPTIONS

In making predictions of the future final energy demand of the Chinese building sector by using the LEAP model, the team set two scenarios, namely a Reference Scenario and an Intensified Energy-saving Scenario. In the Reference Scenario, which is also the benchmark scenario, the relevant policies for building energy conservation and emissions reductions established prior to 2010 are expected to be continually implemented, and no major new policies is expected to be introduced after 2010. The natural progress in energy efficiency technologies for buildings are considered, and but it assumes no major technical breakthrough prior to 2050. People's requirement for the comfortable buildings and good building service levels will be further satisfied through urbanization as well as economic and social development. The Intensified Energy-saving Scenario, also called the target scenario and the scenario that is expected to be achieved, expects a series of policy measures to be adopted to push forward the enhanced energy saving and maximum application of the existing advanced building energy conservation and emission reduction technologies. In addition to meeting the higher requirements for comfort levels, the Scenario aims to significantly reduce the future energy demands of the building sector and realize its sustainable development. By comparing the projected energy demand in the two scenarios, it is feasible to evaluate the energy-efficiency potential of the building sector under the Intensified Energy-saving Scenario and identify the major energy-efficiency opportunities.

The macroeconomic parameters relating to the energy demand of the building sector are mainly population, urbanization rate, GDP, number of persons per household and the proportion of persons employed in tertiary industry. The population size and urbanization rate affect urban and rural population distribution as well as the urban and rural residential building area; the number of persons per household affects the number of urban and

TABLE 4-3. The macroeconomic parameter assumptions

INDEX	UNIT	2010	2020	2030	2040	2050
Population	billion	1.34	1.41	1.43	1.42	1.37
Urbanization rate	%	50	60	68	74	78
Per capita GDP	US$	4,400	8,700	15,400	23,200	32,200
Size of urban household	People	2.88	2.88	2.80	2.73	2.65
Size of rural household	People	3.95	3.66	3.40	3.14	2.88
Proportion of employment in tertiary industry	%	41.0	47.2	53.1	59.4	65.2

Note: per capita GDP is the 2010 statistical data; the proportion of employed persons in tertiary industry in 2010 is adjusted based on the statistical data, but taking into account the migrant workers

rural households; GDP per capita and number of households jointly influence possession of household electrical appliances; and the proportion of employed persons in the tertiary industry will affect the quantity of employed persons in such industry as well as the area of public buildings (see Table 4-3). The macroeconomic parameter assumptions are the same under the Reference Scenario and the Intensified Energy-saving Scenario.

The building activity parameters in this model mainly cover building area per capita, the housing vacancy rate and ownership of electrical appliances per capita. The building activity level is mainly related to the stage of economic and social development. Since the macroeconomic parameter settings are the same under both scenarios, the building activity parameter assumptions are the same. According to data from the *China Statistical Yearbook*, in 2010 the per capita urban residential building, per capita rural residential building and the public building area per employee in the tertiary industry were respectively 26.8 square meters, 31.6 square meters and 38 square meters.[9] Since the per capita GDP in China will reach US$ 30,000 by 2050, approaching the present average level of European countries, it is assumed that in China in 2050 the per capita urban residential building area will be 46 square meters, the per capita rural residential building area 46.3 square meters, and the public building area per employee in tertiary industry 50 square meters. In addition, on the assumption that in 2010 the national vacancy rate of urban residential buildings was 15% (in projecting energy demand, it is assumed that vacant housing has no energy consumption), it is expected that, with the self-regulation of the housing market and the guidance of the relevant policies, the housing vacancy rate will gradually decrease in the future, drop to 0% in 2025 and remain unchanged thereafter. For rural residential buildings and rural public buildings, their vacancy rate will not be taken into consideration for the time being.

Under the Reference Scenario, because of the continuation of the existing policies, new buildings do not include buildings with ultralow energy consumption, existing buildings do not include in-depth energy conservation retrofits, and the retrofit rate of existing buildings is relatively low. Under the Intensified Energy-saving Scenario, a series of policy measures will be adopted to extensively promote passive buildings (passive houses) with ultralow energy consumption, while greater efforts will be devoted to carrying out energy conservation retrofits to existing buildings. Therefore, among the new buildings, the proportion of ultralow-energy consumption buildings, the retrofit rate of existing buildings and the proportion of deep retrofit projects will increase significantly.[10] Under the Reference Scenario, the proportions of new urban residential buildings, of ultralow-energy consumption buildings in new public buildings and of rural near-zero-energy consumption buildings always remain 0; under the Intensified Energy-saving Scenario, the said three proportions will constantly increase to 60% by 2050. Under the Reference Scenario, both the urban residential buildings and the public buildings expect very low retrofit rates and no deep retrofit. Under the Intensified Energy-saving Scenario, the retrofit rates of all types of buildings will quickly increase and reach 75% by 2050; among the retrofitted buildings, the proportion of buildings under deep retrofit will gradually increase and reach 100% by 2050.

For the types of final energy uses of buildings which differ in climatic regions, functions and energy conservation levels (the extent of energy conservation retrofits and the followed energy efficiency design standards), this model sets different energy intensities. Under both scenarios, all the available energy intensity parameters of buildings are consistent.

According to the energy-efficiency levels, this model divides each energy consumption system or piece of equipment in a building into two types, namely the existing type and the high efficiency type. The existing type represents the national average energy-efficiency level of the system/equipment in the base year, while the high-efficiency type represents the most advanced energy-efficiency level of the system/equipment at present. In 2010, the popularity rate of high-efficiency equipment was 0; in the future, this will increase gradually. Under the Reference Scenario, due to the lack of effective policies for product promotion, and with the development of market, the penetration rate of high-efficiency equipment will only reach 40% by 2050. Under the Intensified Energy-saving Scenario, relevant policy measures will be adopted to speed up the deployment of high-efficiency equipment, so the penetration rate of high-efficiency equipment will reach 100% by 2050.

9 Note: According to data from the China Statistical Yearbook, in 2010 the per capita urban residential building area was 31.6 square meters (excluding collective households). If such factors as collective households and the migrant population are taken into account, it is estimated that the per capita urban residential building area was about 26.8 square meters in 2010. In 2010, the public building area per employees was calculated according to the total area of public buildings and the number of persons employed in tertiary industry.

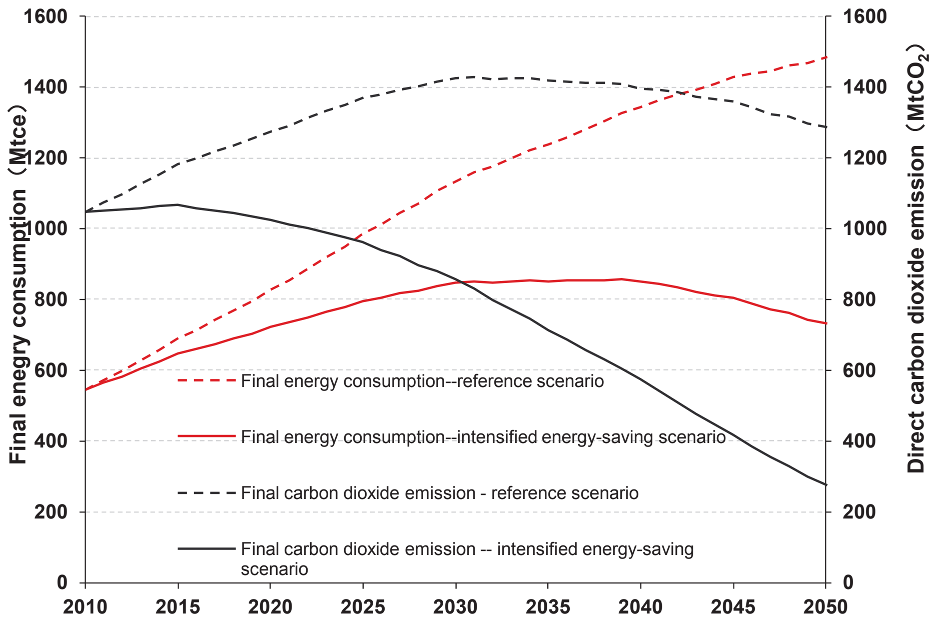
10 Note: The proportion of ultralow energy consumption buildings is an accumulated proportion, which represents the accumulated area of ultralow energy consumption buildings, accounting for the accumulated area of new buildings; the retrofit rate of existing buildings refers to the proportion of the accumulated area of retrofitted buildings, accounting for the total area of existing buildings; and the proportion of deeply retrofitted buildings refers to the accumulated area of deeply retrofitted buildings, accounting for the accumulated area of retrofitted buildings.

4.2.3 ANALYSIS OF THE MODELING RESULTS

According to the modeling results, in the future the final energy consumption of buildings in China will show entirely different development trends under the two scenarios (see Figure 4-2). Under the Reference Scenario, the final energy consumption of buildings will constantly grow from 550 Mtce in 2010 to 1.48 Gtce in 2050, an increase of 172%, during which there is no peak value. Under the Intensified Energy-saving Scenario, in 2050 the final energy consumption of buildings will only be 730 Mtce, representing an increase of 34% against that in 2010. In 2039, the final energy consumption of buildings will reach a peak value of 860 Mtce, 1.6 times that in 2010. It is observed that, under the Intensified Energy-saving Scenario, in 2050 the final energy consumption of the building sector will be 51% than under the Reference Scenario, with an energy-efficiency potential of up to 750 Mtce. In addition, the two scenarios will also see remarkable different development trends of direct final CO_2 emissions of the building sector. Under the Reference Scenario, the direct final CO_2 emissions will first increase, then fall, reaching a peak in 2031. However, under the Intensified Energy-saving Scenario, the direct final CO_2 emissions will constantly fall after 2015 and decrease to 280 Mt by 2015, representing 26% of the 1,050 Mt recorded in 2010.

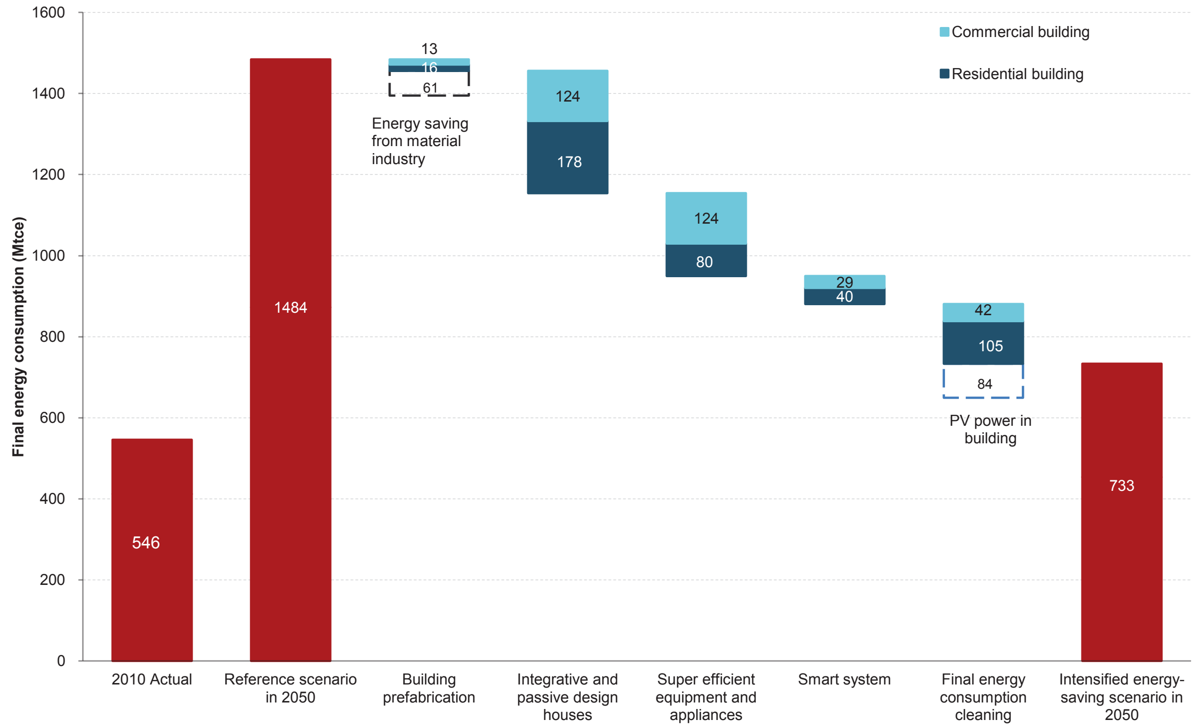
Under the Intensified Energy-saving Scenario, various energy conservation measures will be adopted, including the promotion of prefabricated buildings, the promotion of integrated and passive designs, improvements to the efficiency of energy consumption systems and equipment used in buildings, the development of intelligent systems and the cleaning of the final energy consumption of buildings. Different measures have different energy efficiency improvement potentials. The distribution of energy-efficiency potentials in the building sector in China in 2050 is shown in Figure 4-3. The greatest energy efficiency improvement potential is the penetration of integrated and passive design, which accounts for 40% of the total energy-efficiency improvement potential. The next important energy efficiency potential is improvements to the efficiency of energy consumption systems and equipment used in buildings, contributing 27% of total energy efficiency improvement potential. The optimization of the final energy consumption mode of building and improvements to the renewable energy utilization e and electrification level contribute 20% of the total energy efficiency potential. The vigorous development of such technologies as intelligent control systems and micro-nets contributes about 9% of the energy efficiency improvement potential. The promotion of prefabricated buildings will only di-

FIGURE 4-2. The outlook for final energy consumption and direct CO_2 emissions in the building sector in China



Note: As shown in this Figure, in calculating the carbon dioxide emissions of building sectors, the carbon dioxide emission factors of coal, coal gas, LPG, natural gas and oil products are determined respectively as 2.88 tCO_2/tce, 1.3 tCO_2/tce, 1.85 tCO_2/tce, 1.64 tCO_2/tce and 2.27 tCO_2/tce. The CO_2 emissions generated in electric power production and heating power production are counted into the processing conversion sector, and the final CO_2 emissions of the electric power sector and heating power sector are calculated as 0

FIGURE 4-3. The final energy savings potential for the building sector in China in 2050 under the Intensified Energy-saving Scenario



rectly contribute 4% to the total energy efficiency improvement potential of the building sector in 2050. However, since building industrialization will improve building quality, extend the life of buildings, reduce the quantity of new buildings and cut down the demand for building materials, this measure can indirectly reduce the final energy consumption of the industrial sector by about 90 Mtce, making considerable energy efficiency improvement contributions to the whole of society.

4.3 IDENTIFICATION OF HIOS IN THE BUILDING SECTOR IN CHINA

4.3.1 TECHNICAL HIOS

HIO 1 Promote passive houses

A passive house is a building in which all kinds of energy efficiency technologies have been introduced to optimize the envelope structure and indoor environment, maximize the thermal insulation, heat insulation and airtightness of the building and minimize the requirements for heating supply and cooling. In addition, different kinds of passive building measures, such as natural ventilation, natural lighting, solar irradiation for heat gain and indoor non-heating supply heat source for heat gain, are adopted to achieve a comfortable indoor thermal and humid environment as well as a lighting environment, minimize dependence on the active mechanical heating and cooling system, or completely eliminate such facilities.

Since the world's first genuine passive house was built in Darmstadt, Germany in 1991, passive houses have demonstrated their huge potential for development. By the end of 2013, about 50,000 passive houses had been built globally, half of them in Germany (MOHURD and GEA 2013). Up to now, passive houses have become the building standard with the most extensive extension coverage in Europe. Germany has established clear requirements for the airtightness of passive houses, the total energy consumption of a passive building, the heat requirement for heating, the heating load, and the cooling and indoor comfort levels. For example, total energy consumption of the building (primary energy) is ≤120kWh/m²/year, and the heat requirement for heating ≤15kWh/m²/year (MOHURD and GEA 2013).

Since 2009, the MOHURD has carried out 'China passive low-energy consumption building demonstration projects' in cooperation with the German Energy Agency. At present, some passive houses, including Qinhuangdao 'Zaishuiyifang', Harbin 'Chennengxishu courtyard', Zhuzhou 'Huitianran Urban Park Phase II' and Qinghai 'Lishuiwan community', have been completed and put into use. Passive house pilot projects under construc-

tion can be found in different climatic zones all over the country. The existing pilot projects in China have shown that the penetration of passive houses under existing conditions can significantly reduce the energy consumption of buildings in addition to improving the living environment, and that these passive houses are technically feasible and economically affordable. Technically, it is essential to adhere to the principle of 'giving priority to passive design, and perform active optimization for economic and practical results'. In addition to meeting the local climatic and natural conditions of the construction site, the building sector should, through reasonable plane layout, effectively utilize natural lighting and natural ventilation to improve the heat insulation and airtightness of the building envelope and adopt various passive technological measure, including a solar utilization technique and an indoor non-heating supply heat source for heat gain to maximize building energy efficiency and obtain a comfortable quality of indoor physical environment. The Qinhuangdao 'Zaishuiyifang' pilot project has a heating demand that is only a quarter of the standard for the heating energy consumption in residential buildings as specified in the local building code: 'energy saving by 65%'. In other words, about 70% of energy consumption for heating can be saved (MOHURD 2013).

So far, the per capita building area in China is still on the low side. Given economic and social development and improvements to living standards, per capita building area will further increase in China. If by 2050, the per capita urban residential building area, the per capita rural residential building area and the per employee building area per of the tertiary industry are respectively 46 square meters, 46.3 square meters and 50 square meters, in 2010- 2050, the total residential building area will increase from 40.8 billion square meters to 63 billion square meters, and the public building area will increase from 12 billion square meters to 23 billion square meters. In the next four decades, the number of urban residential buildings will annually increase by more than 1 billion square meters on average (ERI, MRI and LBNL 2016). Under the Intensified Energy-saving Scenario, the proportion of ultralow energy-consuming passive houses among new buildings will be significantly improved. On the assumption that in 2050 the accumulated area of ultralow energy-consuming passive houses will account for 60% of the accumulated area of new urban buildings (residential buildings and public buildings), the accumulated area of near-zero energy-consuming buildings will account for 60% of the stock of rural residential buildings, as estimated according to model, the residential buildings and the public buildings will save 112 Mtce and 104 Mtce of final energy consumption respectively against the Reference Scenario, indicating great energy efficiency improvement potential.

China is facing the following major obstacles in promoting passive houses. First, there is the awareness issue. Due to the brief history of passive house development in China, the whole of society has a low degree of awareness of the benefits of passive houses. Second, there is the technical issue. An integrated design concept and high expertise is generally needed to design passive houses, and there lacks of qualified technical personnel for the design of such houses. Third, there is the standards issue. The current building codes in China mainly specify the requirements for the thermal performance of the building envelope and special energy consumption equipment such as heating and air-conditioning, not requirements for the energy-efficiency level of the whole building. In addition, the current building code lacks encouragement to use such passive solutions as natural ventilation, natural lighting and solar energy to reduce the building's energy demand. Fourth, there is the building materials issue. Energy-efficient building materials, such as high-performance windows and air-sealing products, are in short supply in the market currently, thus affecting the effective implementation of integrated designs. Fifth, there is the construction issue. Passive houses have high demands for the knowledge, skills, and expertise of construction workers.

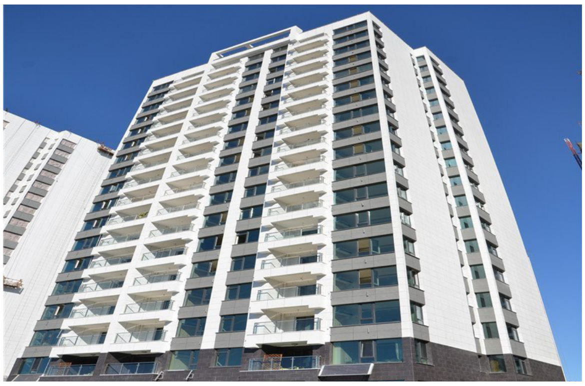
HIO 2 - Popularize super-efficient equipment and appliances

Given the progress in economic and social development, the intensity and scale of economic activities in the service sector will increase, and with it an ever-increasing requirements for energy services, hence the energy consumption demands of office equipment and lighting will further increase. The growth of household incomes will also stimulate the continuous increase in the stock of energy-consuming equipment such as household electrical appliances and lighting facilities. With technological progress, the energy-efficiency level of building equipment has improved. At present, most energy consuming equipment in buildings have some more energy efficient substitutes. For example, organic light emitting diode (OLED) TV sets can save energy by 30% against the present conventional liquid crystal (LCD) TV set. However, on the whole, the penetration rates of super-efficient equipment and appliances are relatively low; therefore increasing the penetration rate of super-efficient equipment and appliances in the building sector will bring about more opportunities for energy efficiency. Certainly, it is very important to select the appropriate energy consumption mode, as well as necessary to promote super-efficient equipment and appliances based on the appropriate mode of energy consumption.

According to the investigation, the efficiency of the present major building energy-consuming equipment

BOX 2. Case Study: Qinhuangdao 'Zaishuiyifang' passive house pilot project

The Qinhuangdao 'Zaishuiyifang' passive house pilot project is located in Harbor district in Qinhuangdao City and its nine buildings have a total building area of 80,344 square meters. The 'Zaishuiyifang' No. C15 Building was the first building constructed according to the German standard for passive houses, with a height of 18 floors and a building area of 6,467 square meters. This project has received a two-star green building label and is certified under the China-Germany passive house standard. According to an evaluation of four aspects of this project (overall energy performance, primary energy demand, envelop structure design and parameters of energy consumption equipment), the heating energy demand, cooling energy demand and the total demand for primary energy are 13kWh/m^2/year, 7kWh/m^2/year and 110kWh/m^2/year respectively, fully in compliance with the comprehensive evaluation requirements specified in the standard for the passive house as a low energy-consuming residential building. The space heating demand of this project is about a quarter that for residential buildings as specified in local standard 'energy saving by 65%'. Its construction costs are only RMB 596 /m^2 (or a 12% premium) higher than those for normal residential buildings. In addition, the indoor PM2.5 level is lower than in the neighborhood of the buildings during periods of heavy haze.



Qinhuangdao passive house project

The major technical features of the Qinhuangdao Passive Houses are as follows:

1) There is no thermal bridge in the high-efficiency external thermal insulation system and the heat-transfer coefficients of the roof, external wall and basement roof are $K \leq 0.15 W/m^2 \cdot k$; the non-transparent external building envelope is completely covered by thick heat-insulating materials; the external layer of insulation materials on the external wall are more than 200mm thick; and blocking measures are used to prevent the formation of thermal bridges by metallic connecting pieces;

2) Double-layer external windows with low-emissivity and high thermal insulation performance are adopted, which have good lighting, thermal insulation and heat-insulating performances, with a heat-transfer coefficient of $k \leq 0.8 W/m^2 \cdot K$, a total solar energy transmittance of $g \geq 0.35$, and a selectivity coefficient of glass $s \geq 1.25$. The external window has the selective transmission for light rays with different wavelengths, which can isolate outdoor solar heat in summer, reflect the near-infrared rays that are radiated by glass indoors in winter, and can also make full use of natural light to meet indoor lighting needs.

3) The buildings have a high level of airtightness. Each building and each residential unit has a continuous and integral air-retaining layer that encloses the whole heating space. When the pressure difference between the indoor and outdoor environments reaches 50Pa, the air exchange ratio per hour does not exceed 0.6 time.

4) Makes full use of renewable energy sources, using solar energy to meet the requirement for indoor heating in winter, use sunlight to meet the requirements for lighting during the day, and install solar water heaters to meet the demand for domestic hot water;

5) In the special indoor energy environment system, space conditioning is provided by a variable-refrigerant-flow air-source heat pump, and the central air-ventilation system includes 75% efficient energy recovery;

6) Perform refined construction, pay special attention to details, and adopt the corresponding measures for thermal bridge blocking, moisture protection, waterproof protection and nose protection.

(Source: MOHURD 2013)

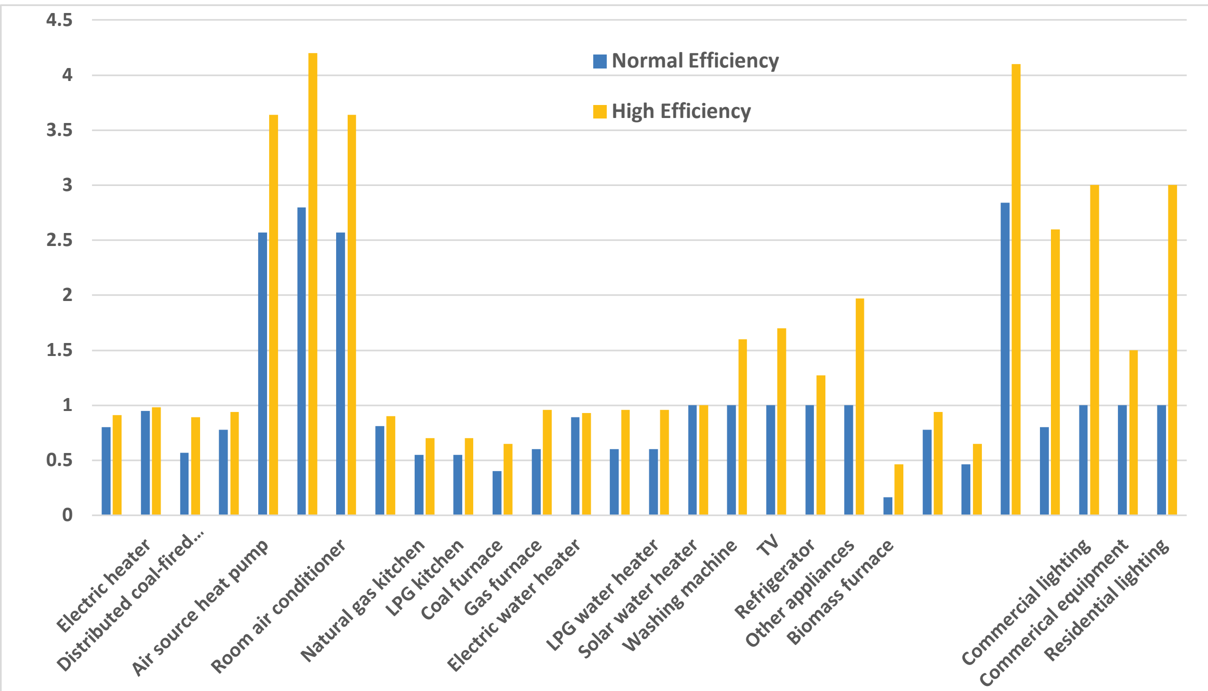
is compared with the high energy efficiency level (the energy efficiency of the advanced products which have appeared in internal markets), as shown in Figure 4-4 (ERI, RMI and LBNL 2016). It is visible that most energy-consuming equipment in buildings still has potential for improvements to energy efficiency. At present, the popularization rate of high energy efficiency equipment is almost 0, but in the future this will gradually increase. In the reference scenario, due to a lack of effective policy on product popularization, and with the self-development of market, it is assumed that the popularization rate of high energy efficiency equipment can only reach 40% by 2050. In the intensified energy-saving scenario, relevant policy measures are adopted to speed up the popularization of high efficiency equipment, and it is assumed that the population rate of such equipment will reach 100% by 2050. According to the results of the model's estimates, in 2050 in the intensified energy-saving scenario, due to the popularization of energy-consuming equipment with high-energy efficiency, the building sector can save final energy consumption of about 200 Mtce against the reference scenario.

There are many kinds of energy-consuming consumption equipment in buildings. On the whole, the current energy efficiencies of appliances, lighting facilities and energy-consuming office equipment in China are generally lower than the most advanced international levels. In general the awareness of energy efficiency labels among Chinese consumers is low. Moreover, energy efficiency labels are available for a few types of appliances and equipment and they fails to provide adequate information to enable consumers to select the most energy-saving products. Furthermore, higher sales price often discourage consumers from purchasing super-efficient appliances and other energy-consuming equipment.

Air source heat pump technology provides a good example about the barriers in China for the wide dissemination of super-efficient appliances.

Heat pumps are designed to move thermal energy in the opposite direction of spontaneous heat transfer by absorbing heat from a cold space and releasing it to a warmer one. The air source heat pump is designed to extract heat from outdoor air, use a blower fan to drive the outdoor air to flow through the heat-collecting device (evaporator of heat pump) installed outdoors, prepare hot water or hot wind through an indoor heat exchanger (condenser of heat pump) and supply hot water or hot wind to use for indoor heat supply. In its actual operation, given the efficiency factors of such components as the motor,

FIGURE 4-4. Comparison of the improvements in energy efficiency of equipment and appliances



Note: The high-energy efficiencies of washing machines, TV sets, refrigerators, other electric appliances, commercial lighting, commercial equipment and residential buildings refer to relative energy efficiencies in comparison with ordinary energy efficiencies and the virtual efficiency improvements caused by the reduction of energy consumption required to provide unit service

compressor and heat exchanger, air source heat pumps can generally reach a heating efficiency, Coefficient of Performance (COP), of 3 or 4. As compared with that of direct electrical heating, to meet the same heat supply requirement, the power consumption of the air source heat pump is only 1/3-1/4 that of direct electric heating, indicating a very remarkable energy efficiency improvement.

Air source heat pumps are highly applicable to multiple climatic regions in China and are the best technology solution for providing heating for buildings in regions without access to a central heating system. Since they can take heat directly from the outdoor air, air source heat pumps may be continently installed for each house or apartment and save building space. In the regions with a minimum winter outdoor air temperature between -10°C and +10°C, an air source heat pump can be used for space heating. Air source heat pumps can have many indoor terminal heating modes. Floor radiant heating and/or indoor machine terminals can be adopted, or a fan coil can be used to direct hot wind to the indoor environment. When floor radiant heating is adopted, the temperature of the hot water heated by the heat pump is controlled at 35°C or so and can meet demand, so that the energy utilization efficiency of the air source heat pump can be significantly improved. The indoor thermal comfortability realized by the floor radiant heating mode can be more easily guaranteed than direct hot air supply, so the mode of 'air source heat pump with floor heating' has more advantages in terms of system energy conservation and indoor thermal comfortability.

For the very cold regions, low-temperature heat-pump technology can be used to improve reliability, safety and energy efficiency for space heating. For example, the air source heat pump technology based on a two-stage enhanced vapor injection variable frequency compressor can be used to enhance vapor injection and change the displacement ratio through the two-stage compression of a single compressor and significantly improve the capacity of the heat pump. Being able to expand the application range of the air source heat pump and significantly improve heating and cooling capacity and energy efficiency under a -25°C to +54°C outdoor environment, this technology can be used extensively in cooling in hot areas and heating in cold areas. As compared with the conventional air source heat pump technology, this technology can improve energy efficiency by 5% to10% under rated heating (outdoor 7°C) conditions. At an indoor environment temperature of -20°C, it can improve heating quantity by 50% to 100% and energy efficiency by 5% to 20% (NDRC 2016). This technology has a high adaptability to outdoor ambient temperatures and can be promoted in most of China's climate areas.

In the Yangtze River Basin region in China, which covers Shanghai, Anhui, Jiangsu, Zhejiang, Jiangxi, Hunan, Hubei, Sichuan and Chongqing and falls within the hot summer and cold winter climate zone, there are six billion square meters of urban residential buildings and about 200 million urban residents. For a long period, the residential buildings in this region have generally featured low indoor temperatures and poor thermal comfort in winter. With improvement in living standards, local residents increasingly demand higher indoor temperatures in winter, so space heating energy consumption can become a major driver to building energy demand increase in this region in the future. To meet the space heating needs in this region, it is not advisable to adopt the large-scale district heating systems as in North China. A better option is decentralized heating modes such as the decentralized adjustable air source heat pump and the gas-fired wall-hanging stove.

According to a recent survey, at present most urban households in the Yangtze River Basin region use electric power or gas-driven decentralized and local heating modes in winter. The indoor temperature in the heating space are only 14°C-16°C in general, while the energy consumption intensity for heating in winter is about 2-4kWh/m^2 - much lower than the energy consumption intensity for heating in urban areas in North China (THURBERC 2013). According to the investigation, if air source heat pump technology is used for heating, the power consumption in each winter is about 6-8 kWh per square meter, equivalent to 2-3 kgce. If a gas-fired wall-hanging furnace is used for heating, average energy consumption per square meter of building area is 3-5 m^3, equivalent to 3-5 kgce (THUBERC 2013). If a large-scale central-heating mode is used for residential buildings with a total area of 6 billion square meters in this region, the heating energy consumption intensity in each winter can reach 8-12 kgce per square meter, which is 3-5 times that of a decentralized heating mode mainly providing electric heating, so that the total energy consumption for heating in this region will increase by 50 Mtce (THUBERC 2013). In other words, for the purposes of heating urban residential buildings in the Yangzi River Basin region, as compared with using large-scale district heating, air source heat pump technology can save 50 Mtce. As compared with the adoption of a direct electric heating technology, on the assumption that the heating efficiency COP of the air source heat pump reaches three, this technology can save two-thirds of power consumption and thus save 24 Mtce of heating energy consumption every year. In addition, it can also help the users save heating expenses. The cost of heating a residential building of 100 square meters with an air source heat pump is RMB 500-600 per winter, while the costs of using gas-fired wall-hanging furnace is RMB 800-1000 per winter. If

the district heating is adopted, a householder has to pay a heating cost of about RMB 1500 for a heating season (THUBERC 2013). It is obvious that using air source heat pump to provide heating for urban residential buildings in the Yangzi River Basin region is the best solution as it is technologically feasible, most cost-effective, and has tremendous energy-saving potential.

For the purposes of the air source heat pump used in the Yangzi River Basin Region, the applications for air conditioning in summer and heating in winter have very similar compression ratio requirements for a vapor compression refrigeration cycle, so the Yangzi River Basin Region is most suitable for winter and summer shared air source heat pump technology. However, when an air source heat pump is used for heating in winter in this region, it is necessary to take into account condensation from the outdoor evaporator in the heat pump. In addition, since the residential buildings in this region generally have poor heat-insulating and airtightness performances, these performances must also be improved so as to reduce the heat requirement of buildings and address the heating needs.

HIO 3 - Carry out deep energy conservation retrofits to existing buildings

Energy conservation retrofits to existing buildings are retrofitting activities performed for the envelope structure, heating, air-conditioning, ventilation and lighting systems of existing buildings which do not comply with the compulsory standards for the energy efficiency of civilian buildings. China has a huge stock of existing buildings. In 2013, the total area of civilian buildings all over the country (not including industrial buildings and productive houses in rural areas) exceeded 54 billion square meters. However, so far, there are only ten billion square meters of energy-efficient buildings in urban areas, accounting for just a third of the total stock of buildings. In addition, in due course, partially energy-efficient buildings will need another retrofit. Some practices in the world have shown that, through deep energy conservation retrofits to existing buildings using integrated designs, in particular in northern heating areas, it is feasible to reduce buildings' energy consumption by more than 30% and significantly improve their indoor comfortability as well as their market values.

For the purposes of energy conservation retrofits to existing buildings, there are different focus points for different climatic regions and building types. For urban residential buildings in the northern region, the focus should be on improving the building envelope structure, promoting heat supply metering, and disseminating the thermal balance transformation to pipeline network. For commercial buildings, the main efforts should be devoted to the energy conservation retrofit of energy-consuming systems, including heating, air conditioning, ventilation, lighting, hot water and electric elevator, so as to improve their operation efficiency. For residential buildings in the hot summer and warm winter and the hot summer and cold winter climate zones, it is necessary to give priority to promote insulation of doors and windows, increasing external shading and increasing the use of natural ventilation. Since urban buildings in northern areas in China are major energy consumers. For example, the primary energy consumption for space heating for urban buildings in the northern region accounted for about 24% of national total building energy consumption in 2013 (THUBERC 2015). The energy conservation retrofit to urban buildings in the northern region can also help improve people's living standards; hence energy conservation retrofit to the existing buildings should be further enhanced.

In general, energy conservation retrofit to the existing buildings cannot be completed by using a single technology; it always involves the integration, optimization and organic combination of multiple techniques with technological strategies, including demand minimization and supply optimization. For residential buildings, the key strategies are improving the thermal properties of the buildings' envelope structures and reducing the available energy loads such as building heating and cooling. In recent years, the Chinese market for building envelope structure technologies such as high-performance heat-insulating materials, Low-E glass, variable sun-shading and airtight sealing have been developing rapidly, providing technical support for tapping the energy-efficiency potential of buildings. For example, an intelligent window, a selective 'thermo-color' window, has been developed and used in the National Renewable Energy Laboratory building in the American Department of Energy. It can change the transmitted heat quantity according to temperature changes on the external window pane while ensuring the normal transmission of equivalent visual light. The amount of solar heat transmitted in cold winter day is more than five times the amount of solar heat transmitted at noon in hot summer.

There are major differences among different regions in the costs of energy conservation retrofits to existing buildings. In the northern regions of China, the costs of envelop structure retrofit, heat supply metering and the thermal balancing of pipeline networks are generally more than 35 US$/m² (RMB220/m²). According to an investigation on the actual costs, in Beijing, Tianjin, Hebei and Heilongjiang, the costs of energy conservation retrofits to existing urban residential buildings range from 40 US$/m² (250 RMB/m²) to 67 US$/m² (420 RMB/m²). The energy conservation retrofit to Hebei No.1 Community in Tangshan City is an example. The building area of this project is about 11,000 square meters; after the retrofit, the heating area reduced to 10,180 square meters. The specific energy conservation measures and the per square

meter total costs were as follows: thermal insulation project outside the external wall: 14.4 US$/m² (91 RMB/m²); roofing transformation work: 8.7 US$/m² (55 RMB/m²); doors and windows modification: 12.5 US$/m² (79 RMB/m²); indoor heating system modification: 14.3 US$/m² (90 RMB/m²); other works: 8 US$/m² (50 RMB/m²); and total cost for energy conservation retrofit: about 58 US$/m² (365 RMB/m²). The space heating consumption of this project before and after retrofit are 25.9 W/m² and 12.0 W/m² respectively; the retrofit reduced the building's energy consumption for heating by 50%, indicating an outstanding energy conservation effect (Liu et al 2012).

The energy-efficiency potential of energy conservation retrofits to existing buildings can be estimated with a model. Assuming that, in the Intensified Energy-saving Scenario, by 2050, most existing urban buildings will have undergone an energy conservation retrofit. Among the building existing in 2050, 75% will have undergone energy conservation retrofits, and 100% of buildings existed in 2010 will have undergone deep energy conservation retrofits. The results of the modelling are that, the residential buildings and the commercial buildings will be able to respectively save 86 Mtce and 32 Mtce of final energy consumption of against the Reference Scenario by 2050, and residential buildings have much bigger energy-saving potential than commercial buildings.

There are certain obstacles to making energy conservation retrofits to existing buildings. First, fund raising is a problem. Such retrofits require a huge investment, so funding is a key issue. In addition, China's existing building stock is huge, with a wide distribution range, at various stages of their use life, different design considerations and standards, a variety of structural forms and complicated property ownerships. For residential buildings in particular, it is very difficult to determine who should be responsible for raising the funds for energy conservation retrofits. Secondly, the market for building retrofit services is still small and weak. In general, single projects of energy conservation retrofits to existing building can only generate small amounts of energy savings and the investment payback periods are often long. There lacks innovation in the investment and financing models, and the market has no strong enthusiasm for such investments. At present, domestic projects of energy conservation retrofits to existing residential buildings are mainly dominated by the public sectors, and the size of government subsidies has an obvious influence on the speed and scale of energy conservation retrofits to existing residential buildings. Third, the foundations for policy making and decision making are weak. The relevant government departments fail to make sufficient investigations or analyze the present energy consumption and retrofit potential of existing buildings, while regional government departments fail to make sufficient investigations to collect relevant information about existing buildings, fail to make adequate analysis of the necessity, feasibility, investment to output ratio and investment payback period of energy conservation retrofit projects, and fail to make clear the key objectives of such projects. Fourthly, there are technical problems. Relevant professionals often lack the integration design concept, which is important to guide energy conservation retrofits to existing buildings.

HIO 4 - Use low-grade industrial waste heat for space heating

Low-grade industrial waste heat mainly refers to the heat quantity included in flue gas with a temperature below 200°C and liquid with a temperature below 100°C, discharged in the industrial process. Due to the low energy grade of such energy resources, it is difficult to use low-grade industrial waste heat in production processes or power generation, so the utilization rates are generally low. In the power sector, for example, only 40% of coal-fired thermal power generation is converted into electricity, the rest being discharged as waste heat. The other industrial sectors, such as steel and petrochemicals, also discharge substantial amounts of waste heat. Most industrial enterprises merely recover residual heat and use it for domestic hot water and plant building heating and only a very small proportion of the total waste heat available is collected and utilized. The demand for low-grade industrial waste heat is seasonal; the demand is relatively low in summer and high in winter.

Urban heating in the north is an important part of building energy use in China. In 2013, the total energy consumption for space heating to urban buildings in the northern regions was 181 Mtce, accounting for 24% of total national building energy consumption in the same year. Among the heat sources for space heating in the northern regions, cogeneration accounted for 42%, coal-fired boilers 48%, gas-fired boilers 8%, and other heat sources 2% (THUBERC 2015). The wide use of coal-fired boilers for space heating is a major cause of high energy consumption and heavy air pollution in Chinese cities. At the same time, the northern regions have abundant industrial waste heat resources. It is estimated that the amount of low-grade industrial waste heat discharged in the heating season in this part of the country (the heating season is calculated at four months on average) is about 100 Mtce (THUBERC 2015). As an important supplementary energy resource, low-grade industrial waste heat can be used in combination with thermal power plants and boilers for the central heating of urban buildings, which is of great significance in reducing energy consumption through central heating and reducing air pollution in northern areas. In fact, urban central heating is the ideal way of using low-grade industrial waste heat in winter. Being compatible and complementary with in-

dustrial waste heat, the regulation and buffering capacities of urban central-heating systems can to some extent accommodate the discontinuous and unstable supply of low-grade industrial exhaust heat.

Since the heat sources with high waste heat resource potential are often kept away from downtown areas, the economic feasibility of the long-distance heat transmission is a key factor affecting the usability of waste heat resources. Tsinghua University has now developed a 'central heating technology based on absorption heat exchange', which can improve the heat-generation efficiency of heat sources (such as thermal power plants) by 40%, and improve the transportation capacity of heat-supply networks by more than 50% (Jiang et al 2014). According to a report issued by the Chinese Academy of Engineering, depending on major temperature differences, the heat exchange technology is able to double the economic transport distance of traditional heat-supply networks. In addition, the research has also demonstrated that the transportation costs of heat-supply pipe networks (including investment in pipe networks, energy consumption during the heat carrier transportation process, and heat radiation loss) decrease with the increase in transport capacity. If the transport capacity is 5000 MW (able to meet the heat supply demand for buildings with an area of 100 million square meters) and the cost for collecting industrial waste heat is less than 2.4 US$/GJ (15 RMB/GJ), the heat supply cost for the long-distance transportation (300 km) of waste heat is lower than that of a natural gas boiler. When the heat supply distance is less than 100 km, waste heat based heating supply is more cost-effective heating supply based on a coal-fired boiler (Jiang et al 2014). In general, the waste heat resources within a distance of 100 km are sufficient to meet a city's heating demand.

Based on investigations in the Beijing-Tianjin-Hebei region, there are 95GW of industrial waste heat resources in this region. If a unified large heat-supply network is built to utilize the waste heat resources from power plants and industries, combined with natural gas-based heat supply for peaking hours, there is enough waste heat to provide heat supply to 2.5 billion square meters of buildings, offering clean heat supply to all the cities at county level or above, part of the villages and towns in the periphery of the large heat supply network and even some rural areas. The investment needs of such a project are estimated at US$ 28.6 billion (RMB 180billion). Such a project can replace 30 million tons of highly polluting coal consumption each year, save 200 million tons from of water being discharged into the atmosphere in the form of steam, and reduce the heat-supply costs to only half of the natural gas-based heat supply costs. If industrial waste heat is used for heat supply all over the northern regions and multiple inter-province large-scale regional heat supply networks are created, the total investment needs will be between US$ 28.6 billion (RMB 800 billion) and US$ 158.7 billion (RMB 1 trillion). These large-scale heat supply network projects can supply heat to about 10 billion square meters of buildings, replace the consumption of 150 million tons of dirty coal and save 1 billion tons of water evaporation each year (Jiang et al 2014). Compared with natural gas-fired heat supply, this project can save more than 100 billion cubic meters of natural gas consumption each year (Jiang et al 2014).

At present, there still exist some mechanism and technology obstacles to using low-grade industrial waste heat for heat supply. Using waste heat for heat supply represents a major opportunity for energy-conservation and CO_2 emissions reduction and it can bring about multiple benefits to the national economy and people's livelihoods. But building such a huge inter-provincial and inter-city infrastructure project needs huge investment, involves enormous interests for various stakeholders, and is very difficult to coordinate, thus strong high-level coordination is needed. The innovative heat-supply mode requests changes to the traditional perception of urban heat supply and energy conservation. However, China lacks heat-supply planning based on low-grade heat sources and the supportive mechanisms for waste-heat based heat supply projects, for example, a pricing mechanism that can objectively reflect the heat supply costs. There are also multiple technical problems to be solved, including how to collect heat from each single waste heat source, integration among multiple waste heat sources, the distribution and transportation of heat, as well as the operational regulation of the industrial waste heat system, so as to promote the harmony cooperation between industrial enterprises and the central heating system.

4.3.2 STRUCTURAL HIOS

HIO 1 Promote building prefabrication

As part of the transformation of the building industry from scattered and outdated handicraft production to massive industrial production based on modern technology, building prefabrication involves constructing industrial and civilian buildings by means of massive industrial production. This is a change to the production mode of the building industry with technical and management innovations as its core elements and an effective way to improve the utilization efficiency of energy resources at the building construction stage. The traditional practice of wet mixing on site usually requires template erection, reinforcement assembling and cast-in-place concrete, which leads to low levels of labor efficiency, high resource consumption, serious environmental pollution and hidden problems in building quality and production safety. In the case of prefabricated buildings, component factory

BOX 3. Case Study: low-grade industrial waste heat utilized for urban central heating in Qianxi County, Hebei Province

There are three major heat sources in Qianxi County, Hebei Province. All of them are small-size coal-fired boilers featuring small boiler system capacity, low heat efficiency, high pollution emissions and high operating costs. Two large-scale steel plants, Jinxi and Wantong, are located a little more than 10 km away from Qianxi County to the northwest. In their production process, the steel plants discharge large amounts of low-grade industrial waste heat, including waste heat from blast furnace washing, steelmaking, continuous casting and cooling, circulating water for cooling blast furnace walls and the desulfurization workshop section. These waste heat sources, in combination with the low-pressure waste heat steam in steel plants, can basically meet the short-term heat demand of house in Qianxi County. As for meeting the heat demand of further increases in building area of the city, absorption heat pumps can be installed at the heating station in the county to reduce the return water temperature of the primary network. The temperature difference between supply water and return water is increased to reduce energy loss in distribution and transmission and to increase the waste heat recovery rate. Industrial waste heat sources can also be used to address long-term heat supply in Qianxi County.

In 2014, Qianxi County implemented a project to use low-grade industrial waste heat in urban central heating, thus achieving a 'green heat supply' without increasing coal and natural gas use. This project is running with 'network-source integrated' commercial operation model, with a total investment of US$ 89 million (RMB 560 million), and is implemented in three phases. In phase I, the heat supply area reaches 3.6 million square meters, with a heating capacity of 150 MW. In phase II, the heat supply area is expected to be 6.84 million square meters, with a heating capacity of 361 MW. In phase III, the heat supply area will be 10.84 million square meters, with total heat supply capacity of up to 561 MW. Phase I of the project has been operational for more than a year, and it can supply heat for 3.6 million square meters of buildings in the whole of Qianxi country, replacing seven sets of 40-ton coal-fired boilers. The industrial waste heat recovery and use is able to save 63,512 tce of coal each year and thus can realize CO2 emissions reductions by 167,580 ton/year, SO2 emissions reductions 543 tons/year, N2O emissions reductions 473 tons/year, and water saving 0.56 million tons/year, with an overall energy-saving rate of over 85%. This project can significantly reduce the PM 2.5 emissions in Qianxi County in winter.

As the next step, Qianxi will make full use of the waste heat from blast furnace slag washing water and from flash steam, install absorption heat pumps in the steel plants, and extract the waste heat from steelmaking, continuous casting and cooling, circulating water for cooling blast furnace walls and desulfurization workshop sections, so as to meet the county's increasing heat load demand. In addition, the building heat exchange station, with its newly increased area at the terminal of the heat-supply network, is required to adopt absorption-type heat-exchange technology to gradually decrease the return water temperature to below 25°C. By increasing the temperature difference between supply water and return water in the primary heat-supply network, it is possible to make better use of the various low-grade waste-heat resources in the steel plants.

Qianxi County is the first demonstration city in Hebei Province, or even in China, that has completely utilized low-grade industrial waste heat for central heating for urban buildings. The practice of Qianxi County has proved that using long-distance low-grade industrial waste heat resources for urban heat supply is technically and economically feasible.

production is a precondition of factory fabrication. Such reinforced concrete components as columns, girders, walls, floors, stairs, galleries and parapets are produced in modern factories in advance and the finished components are then transported to the construction site for fabricated construction, which requires for high levels of technical matching and integration but greatly reduces labor intensity, speeds up construction, saves resources and improves build quality. Building prefabrication requires design standardization, factory production, assembly at construction sites, and the integration of electrical fitment work and process management digitalization such as building design standardization based on final design.

Considering energy consumption in buildings, building prefabrication is mainly designed to perfect the performance of the building envelope. It can also improve building quality, reduce the useful energy load, and decrease the life-cycle energy consumption of buildings by extending buildings' service lives. Moreover, building prefabrication can remarkably reduce the consumption of energy-intensive construction materials and hence indirectly reduce the energy consumption in the industrial sector.

Existing examples of building prefabrication at home and abroad have shown that the prefabrication buildings' use life is 10-15 years longer than that of an ordinary buildings, construction material wastage is reduced by 60%,

construction waste by 80%; and that construction can be greatly speeded up while the construction quality is improved. For instance, it only took fifteen days to finish building a thirty-story hotel building in Xiangyin in Hunan Province (Smith 2016). In China, construction waste is huge, being estimated at 1 billion tons in 2013, of which 26% is produced in the building construction process, 74% in the construction demolition process and only 5% can be recycled (Zheng 2015). Therefore building prefabrication is of great importance in saving resources.

It is assumed that, in the Intensified Energy-saving Scenario, new buildings in cities and towns will be gradually constructed with building prefabrication after 2010 and that all buildings in cities and towns will be constructed in this way in 2050. It is also assumed that the life of buildings constructed in the period from 2011 to 2020 will be extended from the traditional forty years to fifty years and after 2020 from fifty years to seventy years. Besides, China's average per capita floor area in 2050 will reach the lower current levels in developed countries. According to the model, the longer building use life will reduce the area of new urban buildings to be built between 2010 and 2050 by 3.41 billion square meters, thus decreasing the demand for such construction materials as steel and cement and avoiding the energy consumption associated with the production of steel and cement. The construction of 240 million square meters of new buildings in cities and towns can be avoided in 2050, indirectly reducing 60 Mtce for final energy consumption in the industrial sector. Moreover, 30 Mtce of final energy consumption in the building sector will be directly reduced due to building prefabrication in 2050.

Pursuing building prefabrication became a priority of China's building energy conservation during the 12th FYP. At present, more than fifty national prefabricated bases for buildings have been established for the creation of over two hundred national demonstration projects of comfortable districts and the *Standard of Evaluating Industrialized Building* (GB/T51129-2015) has been enacted. According to a preliminary investigation, the total floor area of fabricated buildings in China had reached 35 million square meters in 2015. In the past two years, local governments have set out clear requirements for building prefabrication development, making prefabrication increasingly popular.

However, big hurdles remain in pursuing building prefabrication in China. The current technical standards and guidelines for buildings are not compatible with the technical requirements of building prefabrication, and most current administration systems are applicable to the traditional construction mode, which requires less government intervention and coordination. Besides, lack of close coordination during the design, production and construction stages can lead to longer construction time and higher costs. More specifically, the EPC management mode of integrated design, production and construction of building structure, electromechanical and fitment works are not followed. The technical system and construction method are not renovated for prefabricated part design except 'splitting' the traditional cast-in-situ buildings into components for production and processing, resulting in coexistence of prefabrication and cast in situ in the same project. The degree of standardization of the modular design of construction products is not high, and the components are not standardized and prefabrication cannot take advantage of automatic production lines and scale production (. An industrial supply chain with the integrated development of related industries such as building components and fittings has not be formed, and parties involved in building sector and the industrial sector cannot collaborate with each other effectively.

4.4 POLICY RECOMMENDATIONS

4.4.1 STRENGTHENING THE CAPACITY TO PROMOTE PASSIVE HOUSING

Establish and perfect the technical standards for passive housing in China and set up standards, specifications and construction methods for passive buildings in various climatic regions as soon as possible. Carry out awareness-raising campaigns and training, popularize the idea of 'integrated design' and the design methods of passive buildings, improve awareness of the importance of energy efficiency among real estate developers, building designers and energy efficiency assessment personnel for improving the potential, methods and earnings of building efficiency. Summarize the experience of 'integrated design' and select successful cases, develop comprehensive building energy efficiency assessment tools, and regularly update real estate developers and building designers about national progresses in building energy efficiency improvement, so as to encourage stakeholders to take actions as early as possible. Meanwhile, strengthen the professional training of passive building builders and assess their building qualifications. Enhance research and development into technical products related to passive building, including research and optimization of design procedures, construction and quality control methods for ultra-low energy-consuming passive building systems and develop advanced building envelope components such as vacuum thermal baffles, double-layer Low-E glass, glass window film, light-operated glass windows and air-tight products. Encourage the development of industries producing green building materials, high-performance building envelope components and efficient energy

BOX 4. Case Study: Building Prefabrication Practice of T30 Hotel in Xiangyin, Hunan Province

It took only fifteen days to build a thirty-story hotel with 358 guest rooms in Xiangyin, Hunan Province, by means of prefabrication and installation. A steel-frame structure and curtain wall were used in the hotel construction, 90% of the components being prefabricated and produced in factories. High energy efficiency and low carbon emissions have been pursued throughout the whole construction process, resulting in 10% to 20% reduction in steel use and 80% to 90% decreases in concrete use in comparison similar buildings. During the construction process, there was no fire, water, dust, welding operation on site and concrete or emery cloth polishing was used in the whole construction process, and the construction waste was less than 1% of that produced in traditional construction. The hotel is designed and built to withstand a magnitude 9.0 earthquake, the average building cost is about 1000 US$/m², 30% lower than that of similar buildings in the same areas in China, and 80% to 90% lower than that of similar buildings in western countries (BSB 2013).

Building Prefabrication Practice of T30 Hotel in Xiangyin of Hunan Province

equipment to provide the industrial support for the mass promotion of passive buildings.

4.4.2 IMPROVING THE MINIMUM REQUIREMENTS FOR ENERGY-EFFICIENCY STANDARDS OF APPLIANCES

Gradually improve the energy-efficiency standards of appliances and other energy-consuming equipment so as to reach optimal international energy-efficiency levels. Establish the lowest energy-efficiency standard for common household appliances. Eliminate the low-efficiency appliances and carry out regular assessments continually to raise the lowest energy-efficiency standard. Implement a 'pacemaker' system for energy-efficiency standards. Improve the energy-efficiency labeling system of appliances and other energy-consuming consumption equipment and expand the coverage area of energy-efficiency labeling products. Agree a series of milestones close to world-class appliance markings and send the signals to household appliances and energy-consuming equipment manufacturers to encourage them to research, develop and manufacture more energy-efficient products in advance. The government should distribute public resources to make people aware of the development roadmap of energy-efficient appliances and equipment in time. The government should create the conditions and provide more financial services to encourage consumers to buy more energy-efficient appliances and energy-consuming equipment.

4.4.3 EXPLORING THE DEEP ENERGY CONSERVATION RETROFIT MODE IN RELATION TO EXISTING BUILDINGS

Focus on building external wall insulation, high-performance heat-insulation external windows, air tightness retrofits and efficient heat-recovery fresh air systems with the aim of achieving 'integrated design'. Give priority to adopting passive energy-efficient technologies such as natural lighting and ventilation. Optimize the active energy efficiency technology, and implement deep energy conservation retrofit experiments for residential and public buildings in cold areas. Explore the appropriate retrofit mode and technical route, summarize the expe-

rimental experience in timely fashion and promote it in other suitable areas. Meanwhile, perfect a market mechanism to facilitate building energy conservation retrofits, control the energy efficiency of buildings by means of modernized information technology such as big data, and encourage an innovative investment and financing mode for building efficiency projects. The government has introduced finance and taxation incentive policies to promote building energy conservation retrofits, such as revenue or cost relief, grants or discounts, as well as soft loans, to create incentives to offset the partial costs of building energy conservation retrofits and attracting energy management companies into the building energy conservation retrofit market.

4.4.4 STRENGTHENING THE PLANNING OF USING INDUSTRIAL WASTE HEAT FOR CITY HEATING SUPPLY

Scientifically analyze the heat supply potential of industrial waste heat in the northern heating area, introduce industrial waste heat as a heat source into local heat-supply planning, and create a new model of heat supply with cogeneration and industrial waste heat as the heat supply base, with gas-fired boilers being responsible for pitch peak as well heat pump heating and other efficient scattered heat supply methods as the supplementation. Carry out pilot projects involving cross-region waste-heat supply, such as the 'integrated' heat-supply experiments in the Beijing-Tianjin-Hebei regions. Establish the special leading group to coordinate the relevant sectors and organizations. Work out and introduce a supporting mechanism to guarantee implementation of the new mode of heat supply, such as adjusting the settlement mechanism of the heat source units and heat-supply network units to encourage them to work together in reducing the return water temperature. Institute the deep recycling of low-grade industrial waste heat, with sub-building measurements and household apportioning mechanisms in favor of implementing heat metering and charging systems. Develop the relevant technologies and facilities for low-grade waste-heat supply such as absorption heat pumps, remote transmission and the distribution of massive industrial waste heat, as well as the optimization and adjustment of waste heat systems.

REFERENCES

Building Energy Research Center of Tsinghua University (THUBERC). (2015) *Annual Report on China Building Energy Efficiency 2015*[M]. China Building Industry Press, Beijing.

Building Energy Research Center, Tsinghua University (THUBERC). (2013) *Annual report on China building energy efficiency 2013*. China Building Industry Press, Beijing.

Broad Sustainable Building (BSB). (2013) Modular prefabricated housing construction: limitations and opportunities. http://www.greenindustryplatform.org/wp-content/uploads/2013/07/Broad-Group-BSB-T30-Tower-Hotel_Technical-Briefing.pdf

Energy Research Institute, Rocky Mountain Institute, and Lawrence Berkeley National Laboratory (ERI, RMI, and LBNL). (2016) *Reinventing Fire China: A Roadmap for China's Revolution of Energy, Production and Consumption to 2050*. Sept.,2016.

Jinran Zheng. (2015) 57-Floor Building Goes up in 19 Days. *China Daily USA*. May 5 2015. *Available at:* http://usa.chinadaily.com.cn/epaper/2015-05/05/content_20626039.htm.

IEA, Tsinghua University. (2015) Building Energy Use in China: Transforming Construction and Influencing Consumption to 2050, OECD/IEA, Paris. 2015.

Ministry of Housing and Urban-Rural Development(MOHURD). (2013) *Feasibility study report on popularization of passive residential buildings in China*. December, 2013. Science and Technology Promotion Center, Ministry of Housing and Urban-Rural Development.

Ministry of Housing and Urban-Rural Development(MOHURD). (2014) *Report of National Building Energy Efficiency Inspection Situation on Specialized Supervision and Inspection on Energy Conservation and Emission Reduction in The Field of Housing and Urban-rural Development in 2013*. Building Energy Efficiency and Science & Technology Division, Ministry of Housing and Urban-Rural Development

Ministry of Housing and Urban-Rural Development (MOHURD). (2015) *Report of National Building Energy Efficiency Inspection Situation on Specialized Supervision and Inspection on Energy Conservation and Emission Reduction in The Field of Housing and Urban-rural Development in 2014*. Building Energy Efficiency and Science & Technology Division, Ministry of Housing and Urban-Rural Development.

Ministry of Housing and Urban-Rural Development (MOHURD), German Energy Agency (GEA). (2013) *Handbook for Passive Low-energy Consumption Building De-*

monstration Projects (China-German cooperation). October 2013.

National Development and Reform Commission (NDRC). (2016) Description of Chinese 'Double Top-ten' best energy-saving technologies and practices. http://www.cecol.com.cn/news/20160106/01301706.html.http://www.cecol.com.cn/news/20160106/01301706.html.

National Government Offices Administration (NGOA). (2015) *Annual Statistical Analysis Report on Energy Consumption of Public Institutions in 2014*. December 2015.

Ryan E. Smith. (2016) *Off-Site and Modular Construction Explained.* https://www.wbdg.org/resources/site-and-modular-construction-explained

Wenke Han, Jianguo Zhang, Lijing Gu. (2013) Green Building Actions in China[M]. Beijing: China Economic Publishing House. 2013.

Yi Jiang et al. (2014) *Suggestions on how to comprehensively popularize the use of industrial waste heat for heating to significantly reduce the haze in winter in northern areas*. Chinese Academy of Engineering, 2014.

Yueli Liu, et al. (2012) Energy Conservation Retrofit to the Existing Residential Buildings[M]. Beijing: China Building Industry Press, 2012.

CHAPTER

5

ENERGY EFFICIENCY POLICY AND HIGH IMPACT OPPORTUNITIES IN THE TRANSPORTATION SECTOR IN CHINA

Wenjing YI

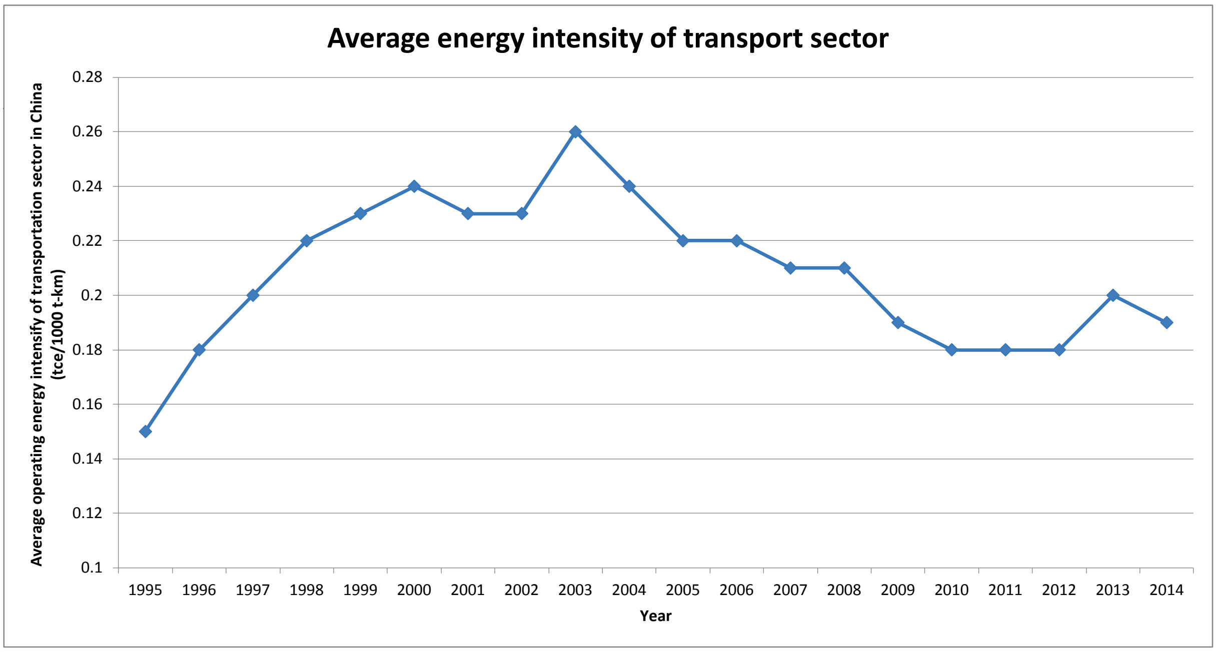
At present, energy consumption in the transportation sector accounts for 10% of national final energy use. Along with economic development and the improvements in living standards, demand for transportation will also increase rapidly. The energy consumption of the transportation sector in the developed countries generally stands at 20%-40% of their final energy consumption. Similarly, the share of transportation energy use in China is bound to increase, and this sector will become a key sector contributing to energy consumption growth. There is also a gap between China and the developed countries in per capita transportation energy consumption. In the major developed countries, per capita transport energy consumption is generally above 0.6 ton of oil equivalent (toe), while in China it was only 0.16 toe in 2010, less than 1/13 that in USA. If the per capita transportation energy use in China reaches 0.6 toe, the current average level in the developed countries, total transportation energy consumption will amount to 840 million toe, assuming the total population remains the same, imposing severe strains on energy security and environmental protection. Therefore, the targets for transportation development should not only be focused on meeting mobility demand, but also on introducing the notion of an energy revolution in order to achieve a breakthrough in energy consumption. This chapter will describe the energy conservation achievements and policies in China's transportation sector, seek to project the country's transportation energy demand in the coming decades and design some pathways for achieving high energy efficiency.

5.1 REVIEW OF ACHIEVEMENTS AND POLICIES REGARDING ENERGY EFFICIENCY IMPROVEMENTS TO TRANSPORTATION IN CHINA

5.1.1 IMPROVEMENT TO ENERGY EFFICIENCY IN TRANSPORTATION

The Chinese government set out forward the mandatory targets of energy conservation and emissions reduction during the 11th FYP, breaking down the national target and setting local targets for all provinces and sectors. The transportation sector began to intensify its efforts and measures for energy conservation and emission reduction measures during the 11th FYP period, implemented key energy conservation projects, and made remarkable progresses in improving the technology and management of energy conservation. However, the effects of these measures and efforts are not sufficient to reverse the overall trend that the transportation sector is heading toward a system of high energy intensity. The shares of the railways and waterways in transport in China are still declining, and the share of public transport is still shrinking due to rapid growth in private cars. Construction of comprehensive transportation systems remains weak. The institutional barriers to freight transport modal shift and the establishment of a seamless transition system for passenger transport have not been eliminated. In recent decades,

FIGURE 5-1. **Energy intensity changes of the transportation sector**



Source: based on data in the China Statistical Yearbook and China Energy Statistical Yearbook

TABLE 5-1. Achievement of main indicators in the 12th FYP for energy consumption and emissions reduction of roads and waterways

INDICATORS	2010	2015 TARGET (%)	2014 (%)	ACCUMULATIVE ACHIEVEMENT
Reduction rate of energy consumption per ton·km of road transport (%)	6.2	10.0	12.3	123%
Of which, passenger vehicles (per person·km)	5.8	6.0	12.4	207%
freight vehicles (ton·km)	6.4	12.0	12.6	105%
Reduction rate of energy consumption per ton·km of shipping (%)	8.9	15	18.74	125%
Of which, inland shipping	10.1	14	21.85	156%
Ocean shipping	8.29	16	16.87	105%
Energy consumption per ton of port throughput (%)	7.55	8	16.02	200%

Note: The reduction rates listed in the table are compared with those in 2005, in percentage points. The levels for 2011-2013 are calculated based on data from the Mid-term Evaluation Report for the 12th FYP of Transportation Development (document JGHF No.2013). The levels for 2014 are calculated based on data from the Statistical Bulletin of the Development of Transportation Sector in 2014

TABLE 5-2. Main targets for railways and civil aviation energy efficiency improvement

INDICATOR	UNIT	2010	2015	2015 TARGET	VALUE IN 2015	TARGET
Energy efficiency of railway transport	tce/ million ton·km	5.01	4.76	5%	4.68	132%
Energy efficiency of air transport	kgce/ ton·km	0.450	0.428	5%	-	-

Data Source: 2015 Railway Statistical Bulletin; 12th FYP for Energy Conservation and Emission Reduction

the overall energy efficiency level of freight and passenger transport has changed from increase to decrease, and the downward trend is slow.[11] Energy consumption per ton·km of transport in 2012 was higher than the level in 1995, but compared with 2005, when the national binding target for energy conservation and emissions reduction began to be implemented, it has been greatly reduced.

During the 12th FYP period, the transportation sector has made steady progress in technical energy conservation, which is mainly reflected in the following factors.

As of 2014, the overall energy efficiency levels of road passenger transport and inland waterway transport, and per port throughput all surpassed the improvement goals set in the 12th FYP and the achievement rates of the goals are 207%, 156% and 200% respectively. Energy consumption per ton·km turnover of freight vehicle and ocean-going shipping achieved their target levels both by 105% (see Figure 5-1).

11 The passenger and freight turnovers are combined according to the method of the China National Statistics Bureau, which the research group has modified based on literature review, with following ratios are used to convert passenger transport volume in person·km into freight transport turnover ton·km: railways 1.5:1, aviation 10:1, waterways 3:1, roads 10:1.

The energy consumption of the national railways in 2015 amounted to 15.70 Mtce, reduced by 834,000 tons from the previous year, down by 5%. Comprehensive energy consumption per transport turnover was 4.68 tce/million ton·km, up by 0.13 tce/million ton·km from the previous year, at a growth rate of 2.9%. Energy consumption of main transport businesses per transport turnover stood at 4.05 tce/million ton·km, 0.15 tce/million ton·km higher than the previous year, or a growth rate of 3.8% (see Table 5-1 and Table 5-2).

In order to address the energy and environmental problems caused by the constant growth of vehicle ownership and to further improve the fuel efficiency levels of vehicles, the Chinese government introduced the *Phase IV Standard for Passenger Vehicle Fuel Efficiency* at the end of 2014, which came into effect on January 1, 2016. The Phase IV Standard introduced the concept of Corporate Average Fuel Consumption (CAFC) and automobile manufacturers are required stay below the maximum limits for CAFC. The CAFC of each manufacturer is calculated based on the fuel efficiency of each type of passenger vehicles they produce and the vehicle type structure of their vehicle production. The CAFC standard ensures the overall fulfillment of the vehicle energy conservation objective, and leaves greater flexibility to vehicle manu-

factures on their compliance strategy. Hence, it helps promote technical progress and vehicle type mix optimization in the auto-manufacturing industry, as well as the coordinated development of traditional vehicles and new energy vehicles.

TABLE 5-3. Reductions in Corporate Average Fuel Consumption (CAFV)

YEAR	RATIO BETWEEN ACTUAL CAVP AND THE TARGET LEVEL OF CAFV
2012	109%
2013	106%
2014	103%
2015 and after	100%

Data source: Standard for Improving the Fuel Efficiency Levels of Passenger Vehicle

Statistics indicate that the CAFC of new passenger vehicles made in China was 7.22 L/100 km in 2013. In particular, the level of joint venture brands was 7.30 L/100 km, the level of Chinese brands 6.95 L/100km, and imported automobiles 9.05 L/100 km. To achieve the target of lowering the fuel consumption level of passenger vehicles to 5 L/100 km by 2020 set by the Chinese government for the 13th FYP period, the fuel consumption level of new vehicles should be reduced by 6%-7% annually on average. Without the contribution of new energy vehicles, however, this objective will be hard to realize (see Table 5-3).

5.1.2 REVIEW OF MAIN POLICIES IN PROMOTING TRANSPORTATION ENERGY EFFICIENCY

The transportation sector has experienced some leapfrog development after the reform and opening-up. Rapid development also brings about many problems in energy conservation and emissions reduction, such as poor transportation mode mix, high energy intensities, incomplete energy consumption standards and labels, etc. To tackle these problems, the Chinese government has enacted various policies to promote energy conservation and emissions reductions in the transportation sector.

Institutional setup

The *Law on Energy Conservation*, revised in 2007, specified the energy conservation tasks of the transportation sector. In order to implement the relevant requirements of the revised *Law on Energy Conservation*, relevant transportation sub-sectors have made their own energy conservation and emissions reductions plans and set their energy conservation objectives. In 2007, the Ministry of Railways issued the *Suggestions on the Implementation of Strengthening Railway Energy Conservation*, and released the *Energy Conservation and Comprehensive Utilization Plan for Railways during the 11th FYP Period* and the *Environmental Protection Plan for Railways during the 11th FYP Period*. These documents set the following targets: energy consumption per RMB of transportation revenue should be reduced by 20% compared during the 11th FYP period from the level in 2005, water consumption per person·km and per ton·km of transport turnover should be reduced by 30%, and gross emissions of main pollutants should be reduced by 10%. In 2008, the Ministry of Transport enacted the *Measures for the Roads and Waterways Transportation Sector to Implement the Law of Energy Conservation*, and released a *Medium and Long-term Development Program for the Energy Conservation of Road and Waterway Transportation*. The documents set the following main objectives of energy conservation and emissions reductions for road and waterway transport: compared with 2005, by 2010 and 2020, the energy consumption per ton·km of road freight transport should decrease by 5% and 6% respectively; the energy consumption per ton·km of waterway transport shall be reduced by 10% and 20% respectively. In particular, the energy consumption per ton·km transport turnover of sea-going ships should be reduced by 11% and 20% respectively; while those for inland shipping are 8% and 20% respectively. The comprehensive energy consumption per ton of port cargo throughput should be reduced by 5% and 10% respectively. The Civil Aviation Administration established a leading group for energy conservation and emissions reduction in August 2008 and released the *Notice on Comprehensively Carrying out Energy Conservation and Emissions Reduction of Civil Aviation* and the *Energy Conservation and Emission Reduction Plan for Civil Aviation during the 11th FYP Period*. Energy conservation and emissions reduction was carried in every aspect of civil aviation. In accordance with the *11th Five-Year Development Plan for Civil Aviation*, by 2010, the energy efficiency of civil aviation should be improved by 10% from the 2005 level (per ton·km oil consumption for airliners and per person/time electricity consumption level for airports), striving to reach 20% improvement by 2020.

Improving transportation energy conservation standards and labeling

Fuel economy assessment is organized for all vehicles in operation. In 2007, the Ministry of Transport proposed the *Special Action Plan for the Fuel-efficiency-based Market Access and Exit of Operating Vehicles*. Afterwards, the Ministry of Transport also issued supporting policies for the implementation of the *Special Action Plan*, including the *Administration Measures for Inspecting and Monitoring the Fuel Efficiency Levels of Road Transport Vehicles* and further defined the working procedures and specific requirements of all stages in the implementation process, which provided institutional guarantees for the inspection, su-

pervision and administration of the fuel efficiency performance of on-road vehicles. The Ministry of Transport released the *Scheme for Economic Incentive Policies for the Early Phase-out of Energy Inefficient Vehicles* (draft).

Another important policy is improving the fuel economy standard system of vehicles and implementing the fuel consumption transparency and labeling system. In 2005, the *Limits of Fuel Consumption Levels for Passenger Vehicle* were jointly enacted by the General Administration of Quality Supervision, Inspection and Quarantine and the Standardization Administration. In 2007, the Standardization Administration released the *Limits of Fuel Consumption Levels for Light Commercial Vehicles*. In 2009, the Ministry of Industry and Information Technology enacted the *Administrative Provisions for the Fuel Consumption Labeling of Light Duty Vehicles*. These provisions clearly defined the inspection, reporting, filing, labeling, publication, supervision and penalties, etc. regarding the fuel consumption level labeling of vehicles, further improving the automobile oil consumption transparency and labeling system.

The implementation of pilot and demonstration projects

a. A program of building pilot cities for low-carbon transportation systems was implemented. As many as 26 cities have participated in the pilot work and shared their experiences. b. The green and low-carbon transportation regional and thematic pilot work. Ten cities, including Chongqing and Xiamen, have been selected for the regional pilot work. Four ports, including Tianjin and Qingdao, and six highways, including Guangdong's Guangzhou-Zhongshan-Jiangmen Expressway and Yunnan's Maliuwan-Zhaotong Expressway, have been included in thematic pilot programs. c. Special low-carbon action for Top 1,000 Enterprises in respect of vehicles, shipping, roads and ports. d. The pilot project of energy consumption data collection and monitoring of key enterprises. The pilot project was coordinated by four provincial transportation departments and the participants included 27 road transport enterprises, 14 waterway transport enterprises, and 42 port operation enterprises. The energy consumption of these enterprises was monitored, and the data collected and analyzed.

Policy measures for key fields

Priority is given to public transit development. The General Office of the State Council forwarded the suggestion of the Ministry of Construction to give priority to the development of public transit in September 2005, and issued suggestions for improving public transit infrastructure, optimizing public transit structure, guaranteeing road use priority public transit vehicles.

The restrictions on small-engine vehicles were abolished. Based on the suggestions of the NDRC and other government agencies, the General Office of the State Council announced the government policy of encouraging the use of small-engine vehicles for energy conservation and environmental protection in December 2005. The suggestions proposed the formulation of relevant supportive policies and measures and requested local governments to abolish various restrictions on small engine vehicles, which are often of high energy efficiency and low pollution emission.

Phasing out outdated vehicles and equipment. The Ministry of Transport issued the *Announcement on Launching the Implementation Scheme on Early Elimination of Single-hull Oil Tankers for Domestic Voyages* in 2009. This document provides basis for the compulsory elimination of inefficient and outdated ships, further shortens the service lives of single-hull oil-tankers, and encourages shipowners to construct and use oil tankers that comply with international standards and the national inspection criteria for domestic shipping.

Another priority area is strengthening the energy conservation management of transportation. Road transportation management is optimized to achieve the targets of energy conservation and emissions reduction through the following measures: developing express cargo delivery and the construction of logistics information platforms, improving the mileage and capacity utilization rates of freight vehicle, enhancing the actual load rate of passenger vehicles through intensive management, and implementing electronic toll collection networks for highway usage. The fuel efficiency of civil aviation is increased by retrofitting aircraft, accelerating aircraft upgrading, and phasing out highly energy-inefficient and obsolete aircrafts.

Fiscal and tax policies. The Chinese government has enacted a subsidy policy to promote energy efficiency. Approved by the State Council, the special fund for the retrofitting of obsolete ferries in rural areas has been established and the funding source is the vehicle purchase tax. A document on the *Management Measures for the Use of the Special Subsidy Fund for Obsolete Ferries in Rural Areas* has been published. The Ministry of Finance and the Ministry of Science and Technology had enacted a *Notice on Carrying out the Demonstration, Promotion and Pilot Work of Energy Conservation and New Energy Automobiles* and *the Interim Methods for the Management of the Fiscal Subsidy Fund for the Demonstration and Promotion of Energy Conservation and New Energy Vehicles*.

Advance the development of road swap trailer transportation. Actively coordinate with relevant sectors and establish the special fund for pilot swap trailer transportation, remove the barriers to the mandatory traffic lia-

bility insurance system for trailers, select and release two batches totaling 75 recommended models of swap trailer transportation, determine two batches of 95 projects incorporated into the national pilot swap trailer transportation, driving eight provinces (autonomous regions and municipalities directly under the central government), including Shandong, Jiangsu, Fujian, and Guangdong, to initiate provincial pilot swap trailer transportation.

Promote the application of natural gas equipment in the transportation sector. The government organizes pilot for the promotion of natural gas automobiles in intercity passenger and freight transport and explores the potential of using LNG as a fuel for shipping, including a research project and pilot operations of LNG-based inland shipping.

Establishing a special fund mechanism

The government has established and is improving a special fund incentive mechanism for energy conservation and emissions reduction in transportation. The Ministry of Finance and the Ministry of Transportation jointly established the special fund for energy conservation and emissions reduction of transportation in 2011 and selected the priority areas for implementation. Since the establishment of the special fund, the concept of offering rewards, instead of subsidies, has been implemented for a total of 413 projects. The total amount subsidy fund distributed is RMB 750 million, realizing an annual energy conservation of 158,000 tce, 262,000 toe of fuel consumption switch to less carbon intensive forms of fuel, and 699,000 tons of CO_2 emissions reduction. During the 12th FYP period, the central government allocated in its budget a total of RMB 3.23 billion for energy conservation and emissions reduction in transportation. Jiangsu, Shandong, Hubei and a few other provinces also established a special fund for energy conservation and emissions reduction in local transportation. This gives full play to the crucial role of the special fund for energy conservation and emissions reduction in social and economic development, effectively bringing about the in-depth promotion of transportation energy conservation and emissions reduction work.

5.2 PROSPECT FOR ENERGY CONSUMPTION IN THE TRANSPORTATION SECTOR (TWO SCENARIOS, BY 2050)

5.2.1 METHODOLOGY

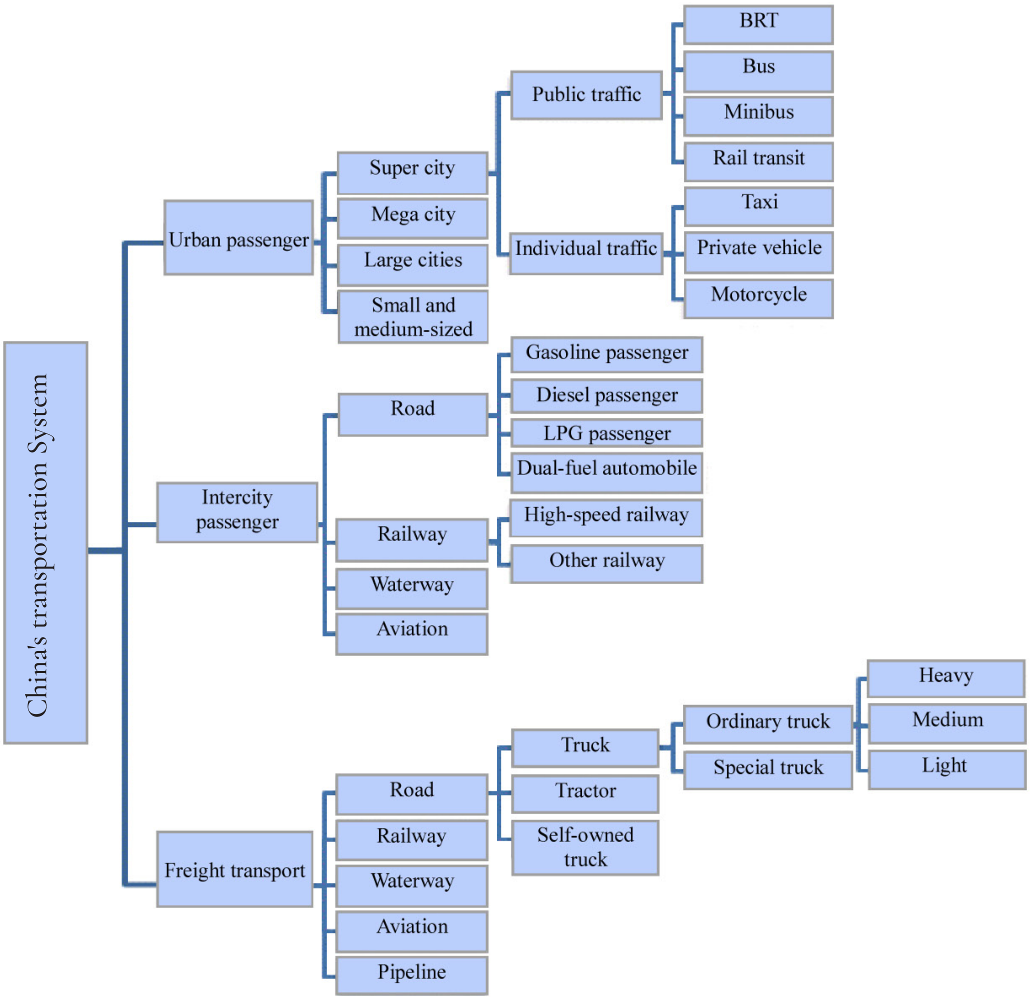
Along with economic and social development and improvements in living standards, passenger and freight transportation demand will see sustained and steady growth. Along with continuous improvement in the transport system, the future growth momentum of energy consumption in China's transportation sector will be strong. This study to project the future energy consumption forecasts for the Chinese transportation sector is mainly based on scenario analysis using the Long-term Energy Alternative Planning (LEAP) system. The scenarios are designed to take full consideration to the following factors: the social and economic development targets set in government plans, the latest progresses in resources, environment and technology, geopolitics both home and abroad, the selection of different industrialization and urbanization pathways, and expert judgments and analyses regarding potential levels and trends in transportation energy consumption and carbon emissions.[12]

This study divides the Chinese transportation system into urban passenger transportation, intercity passenger transportation and freight transportation, and conducts a comprehensive analysis of the demand for transportation energy consumption. In the case of urban passenger transportation, the analysis focuses on the energy conservation and emissions reduction potential from the optimization of the transportation model in different city types, fuel switch and technical advances. For intercity passenger transportation and freight transportation, the analysis focuses on the energy conservation and emissions reduction potential from the optimization of and changes to roads, railways, waterways, aviation and other modes of transportation and technical advances. Accordingly, the projection of energy demand in the transportation sector also divides into energy consumption for urban passenger transportation, intercity passenger transportation, and freight transportation (see Figure 5-2). Railway transportation includes energy consumption during transportation (traction and auxiliary travel), but excludes energy consumption during auxiliary processes (while in stations); road transportation energy consumption refers especially to the fuel consumption of operational road vehicles; waterway transportation energy consumption mainly refers to the fuel consumption of inland river, coastal and ocean-going ships; aviation transportation energy consumption refers to the fuel consumption of civil aircraft; and urban passenger transportation energy consumption refers to the energy consumption of public transit in urban areas (buses/electric buses, taxis), rail transportation, private vehicles and motorcycles.

Transportation energy consumption in China's existing statistics only includes the energy consumption of operational vehicles, including public transport, private vehicles, and vehicles of industrial enterprises. However, energy consumption in stations, like the supply of heating,

12 *The base year of this research is 2010.*

FIGURE 5-2. Transportation Model Framework



lighting and buildings, is also included. In order to better reflect energy consumption in transportation, data from the energy balance sheet are adjusted based on technical parameters, including vehicle fuel economy, annual travel mileage of vehicles, empty trip ratio, load rate, etc. By linking energy consumption to the number of vehicles and the relationships between transportation activity levels, transportation structures and energy consumption intensities, data for the base year are adjusted for projections of future energy consumption. During the data adjustment process, different energy types are checked against the number of vehicles, running mileage, fuel consumption per hundred kilometers, turnover, overload, and empty trips. The connection between transportation turnover and vehicle energy consumption is analyzed. For example, when calculating the diesel consumption of freight trucks, it was found out that in 2010, there were 10.5 million trucks in operation in China, including 9.96 million ordinary trucks and 540,000 special trucks. The correlation is made by combining the average figure for tonnage, annual trip distance, empty trip ratio, and actual load rate of different types of trucks with the freight turnover (4.4 trillion ton kilometers in 2010). Then a correction is made to diesel consumption in the energy balance sheet in accordance with the total annual vehicle kilometers traveled (VKT) on the basis of the annual mileage of the vehicle and the number of vehicles, as well as fuel consumption per hundred kilometers, actual load rate, etc. Through this method, a connection is established between vehicle, turnover and energy consumption data. In the future, the energy consumption of road freight can be added bottom-up on the basis of the variation trend and the potential of a series of physical parameters such as number of vehicles, fuel consumption per hundred kilometers, annual running mileage, actual load rate, etc. (see Figure 5-3).

After adjustment, the energy consumption of the transportation sector in China in 2010 was estimated as 306 Mtce, accounting for 10% of the national final energy consumption. Based on the quantity of equipment, fuel

FIGURE 5-3. Establishing the connections between turnover, energy consumption and vehicles

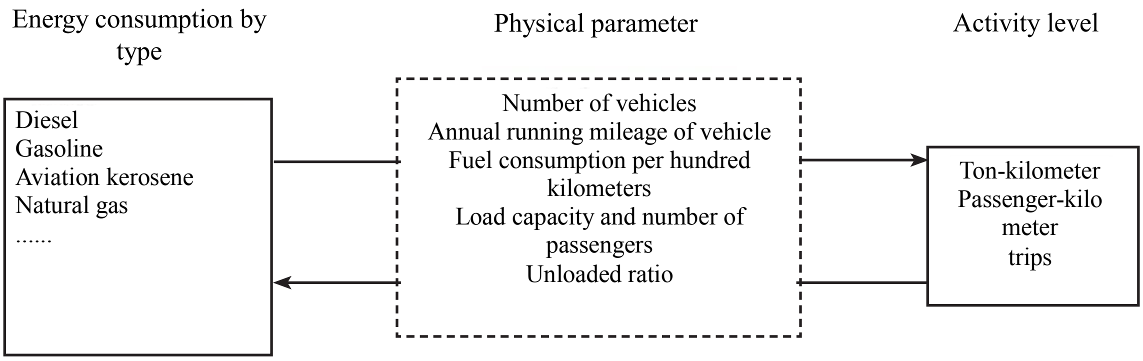


TABLE 5-4. Energy consumption for each type in transportation sector after adjustment in 2010: 1,000t (tce)

GASOLINE	DIESEL	KEROSENE	FUEL OIL	LPG	COAL	NATURAL GAS	HEATING	ELECTRIC	TOTAL
99,200	154,040	23,560	18,380	580	250	4,490	559	2,850	306,330

efficiency, load rate, unloaded ratio, actual load rate and other physical parameters, total energy consumption is allocated to each transportation mode and sub-sector by a combination of top-down and bottom-up methods (see Table 5-4).

5.2.2 KEY ASSUMPTIONS

This study makes the following assumption about economic and social development before 2050. By that year, China will reach the economic level of a moderately developed country at that time, with a GDP of US$ 44 trillion, a per capita GDP of US$ 32,000 (at constant prices in 2010), and an urbanization rate of 78%; and the environmental quality will be fundamentally improved. China will realize the vision of Beautiful China: blue sky, green land, green hills, clear water, livable environment, and high work satisfaction. China will construct a modern energy production and utilization system with advanced concepts, high-efficiency, low-carbon emissions, clean and environmentally friendly, advanced in technology, and cost-effective.

Economic and social development is a major driver for transportation demand. In the future, energy consumption in the transportation sector will mainly be related to transportation demand, including activity level, transportation structure and efficiency of equipment.

Activity level is the most important factor affecting future energy consumption in China's transportation sector. The leading driver of activity levels is GDP. This study mainly adopts the methods of historical trend regression, elastic analysis and reference to international experience, to determine the freight and passenger turnover of the transportation sector in China by 2050. The factors affecting passenger and freight turnover also include changes in the national economic structure, optimization of industrial mix, and emerging new technologies like 3D printing. The changes in economic structure and the transformation in growth patterns may reduce the freight transportation demand for such basic materials as steel and cement compared with the Reference Scenario, and the contents and distances of freight transportation will also be changed. After the possible optimization of industrial mix, the distance between the production and consumption areas can be shortened. Production and consumption will be conducted locally and near each another, to reduce the demand for long-distance and large-scale transportation of goods. Technologies of the third industrial revolution like 3D printing can help promote local production and reduce freight transportation demand. The rapid development of information and communication technologies may reduce the demand for intercity passenger travel services. In addition, ICT technology, home offices, improvements in logistics, better urban planning and layout and other factors will affect the travel activity levels of urban citizens.

Optimization of transportation structures may bring about huge energy savings, but it has a longer implementation cycle and faces more difficulties. Due to the current status of the transportation infrastructure and the growing service demand in China, there is great potential for changing the transportation structure. The leading directions of change include replacing road freight transportation with railways and waterways transport, improving freight vehicle structure by promoting larger trucks, increasing the role of pipeline transportation, replacing

civil aviation and road transportation with high-speed railways in intercity passenger transportation, increasing the share of public transit in urban passenger transportation, reducing use of private vehicles and taxis, and discouraging the ownership and use of private vehicles. The transportation structure of the future is analyzed by taking full consideration of the existing traffic infrastructure plan, experiences in developed countries, domestic resource endowment and geographic conditions.

Efficiency improvements provide an effective instrument for slowing down the increases in the energy consumption of the transportation sector. The influence of efficiency improvements on energy consumption comes not only from the efficiency improvements to transportation equipment, but also from the influence of advanced management technologies such as swap trailer transportation, logistics information technology on energy consumption in the transportation sector. Drop and pull transportation can improve the intensity of road freight transportation, reduce the vacancy and improve the utilization rate of logistics infrastructure, including vehicles, parking areas, and warehouses, and reduce the energy consumption of vehicles, infrastructure construction, maintenance and operation. Modern information network-based intelligent transportation systems can improve efficiency, reduce the empty trips of vehicles and achieve the goals of energy conservation.

In order to better grasp the developing trend of transportation energy demand in China and discuss the influence of policies on that demand, and in designing the scenario, the research group has compared the evolution of the transportation sector at home and abroad and fully considered the evolution of the new technologies. The policy implementation rate is also increased to increase the energy efficiency of the Chinese transportation sector in the future. Based on these factors, the research team designed two scenarios:

The Reference Scenario. This scenario assumes that the main social and economic objectives of the government can be realized smoothly, and that urbanization and industrialization will be the main features of China's socio-economic development during the 13th FYP period and the decades to come. In the transportation sector, such a Scenario has the following implications: the construction of infrastructure such as roads, bridges, railways, civil aviation, will progress smoothly; high-speed railways and expressways will maintain the current trends of rapid growth; the construction of regional aviation will continue at high speed; and the ownership of private vehicles will constantly rise as residents' incomes increase. After industrialization generally completes by 2030, the growth in passenger and freight transportation service demand will be slow down. Within the modelling period, no disruptive change or major technical breakthrough will appear in the Chinese economic system, industrial mix, passenger or freight transportation structure, the energy efficiency level in different transportation modes, as well as the development of alternative fuel technologies, although some gradual advancement is expected.

Intensified Energy Conservation Scenario (the IEC Scenario). Compared with the Reference Scenario, this scenario includes important breakthroughs in energy conservation and low-carbon technologies and their wide application. Important measures are also taken to guide consumer behavior change for sustainable consumption, promote improvements in energy efficiency, optimize mode of transportation, encourage the use of clean and high-efficient transportation equipment, and promote technology progress in the transportation sector. Another assumption is that the government's policies for the economic structure optimization and promotion of the energy revolution will achieve remarkable effects. In this scenario, the international environment is more supportive for the development of clean and low-carbon technologies. International technical and funding cooperation will lead faster progresses in the research and development of new technologies for low-carbon development. Also, it is assumed that the Chinese transportation sector realizes revolutionary transformation: under the precondition of meeting the established economic and social objectives, the sector also sees great improvements in its activity level, model structure, and energy conservation technologies.

5.2.3 ANALYSIS OF THE MODELING RESULTS

Transportation energy consumption and oil use maintains constant growth in the Reference Scenario

In line with the existing pattern of economic and social development, more people will move into large cities and eastern coastal regions, and no breakthrough is achieved in industrial transformation or upgrading. To meet the mobility demand, the growth rates in transportation turnover will be doubled. In order to meet the demand for transportation services, by 2050, the freight turnover will increase 3.9 times, passenger turnover 4.9 times, and the ownership of private vehicles 5.9 times (see Figure 5-4).

By 2050, energy consumption in the transportation sector will reach 1.35 Gtce, an increase of 3.4 times from 306 Mtce in 2010. The average annual growth rate between 2010 and 2050 is 3.8%; specifically, the speed of growth before 2030 will be faster and the annual growth rate will exceed 6%. The growth speed during 2030-2050 will become slightly lower, with an annual growth rate of about 1.5%. Energy consumption in transportation is unlikely to peak before 2050. In the final energy consumption mix, the consumption of diesel will be 617 Mtce by 2050,

double the diesel consumption in 2010 and accounting for 45.7% of final transportation energy consumption; the share is slightly lower than the level of 50.3% in 2010. Although private vehicle ownership increases 5.9 times, the consumption of gasoline only increases 1.2 times, with gross consumption at 273 Mtce, the second largest fuel type in transportation energy consumption. This reflects improvements in fuel economy and fuel substitution. Natural gas consumption will increase from approximately 1% in 2010 to 13.3% in 2050, reaching 179 Mtce, or 134.9 billion m³ of natural gas. Natural gas, as the alternative fuel for vehicles and ships, will be of strategic importance if urban air pollutions are to be alleviated. The consumption of aviation kerosene will increase significantly due to the rapid development of air transport, reaching 148 Mtce in 2050, accounting for 11.0% of final transportation energy consumption. Growth of electricity consumption will be limited, only accounting for 3.0% of final traffic energy consumption in 2050, mainly due to the absence of technology breakthroughs in electric vehicles. In addition, bio-fuel use will see a slight increase. Oil products remain the main fuel for transportation sector. The proportion of fossil fuel will slowly reduce from 97.3% in 2010 to 81.0% in 2050, when oil product consumption will be 1.09 Gtce. Major changes will take place in the shares of different oil products. The ratio between gasoline and diesel consumption will change from 0.64 in 2010 to 0.44 in 2050. The proportion of diesel in the consumption of oil products will experience big changes, thus resulting in great challenges to the oil-refining industry.

FIGURE 5-4a. Change in transportation energy demand and energy mix in the reference scenario

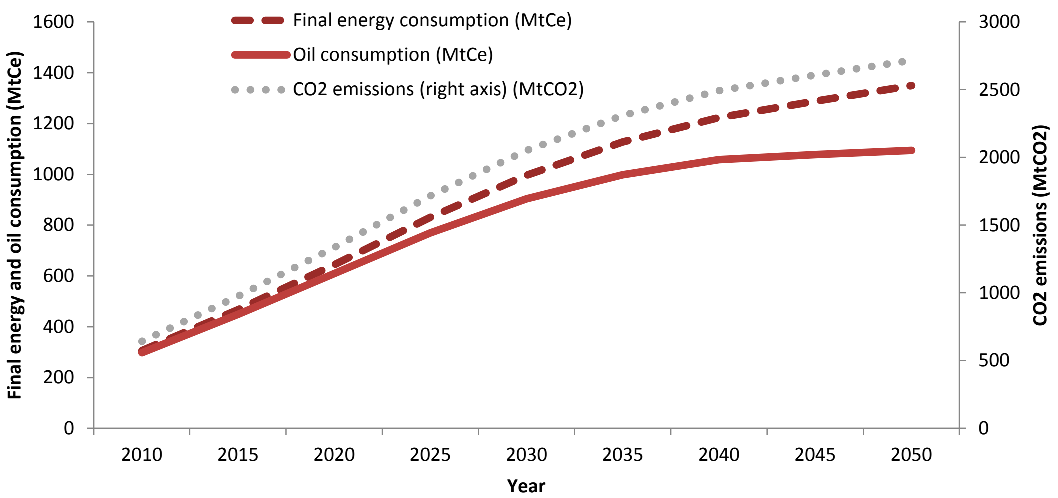
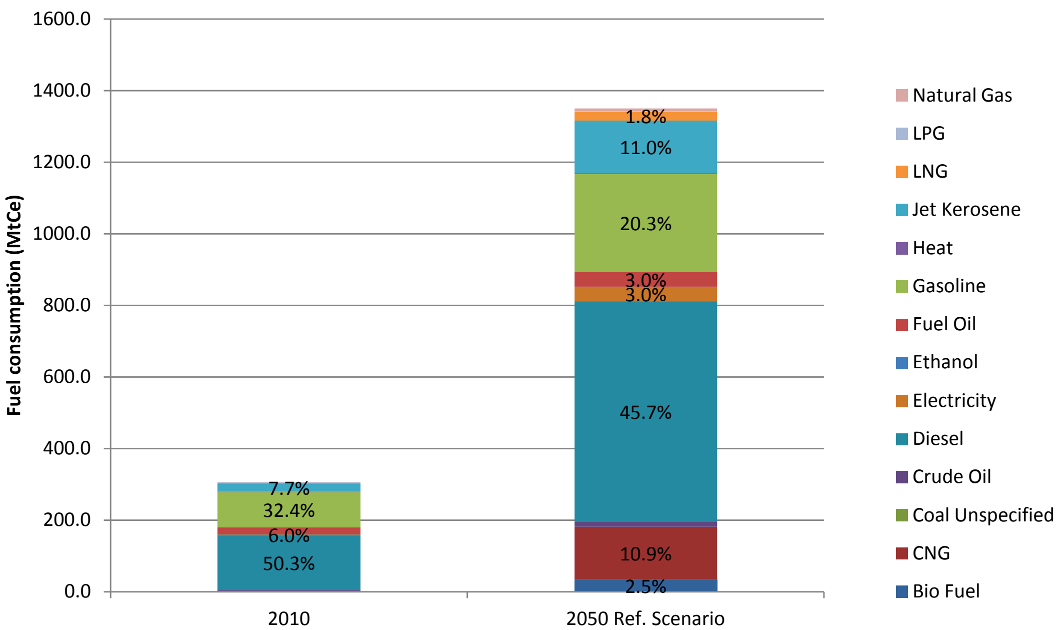


FIGURE 5-4b. Final energy use of the transportation sector



The freight transportation sector remains a major source of transportation energy consumption. Freight transportation will pursue higher levels of efficiency and convenience. The proportion of waterways and railway freight transportation will shrink gradually, while road freight transportation will see its share increasing yearly. In approximately 2030, road will overtake waterways and become the most important mode of freight transportation, and the transportation energy consumption intensity of road trucks is much higher than that of waterway shipping. Therefore, the freight transportation is actually developing towards higher energy intensity. Accordingly, the energy consumption of road freight transportation will be 670 Mtce, accounting for more than 75% of freight transportation energy consumption and approximately 50% of final transportation energy consumption. Both the energy consumption and its share will be very considerable. In terms of the different fuels used for freight transportation, diesel will be the most important fuel, accounting for 74% of freight transportation energy consumption in 2010 and 62% in 2050. The main energy alternative to diesel is natural gas. The vehicle models uses will be mainly heavy trucks and light trucks. The organization and efficiency of freight transportation logistics are poor, and the development level of third-party logistics is low. Before 2050, this will see some improvement, but there will be no fundamental change to the dominant role of road transportation in freight transportation.

Intercity passenger transportation energy demand will see a strong momentum for growth and a shift towards high levels of efficiency and speed. The proportion of waterway and railway passenger transportation will decline year by year. Aviation's share in passenger transportation will increase to 20% by 2050, but its share of energy consumption in intercity passenger transportation will rise to 56%. Meanwhile, the share of road passenger transportation will remain stable and it will continue to be the most important mode of passenger transportation. Road transportation will undertake 53% of intercity passenger transport in 2050 and its share in intercity passenger transportation energy consumption will be 37.4%. The passenger transportation turnover undertaken by the railways will be reduced to 27% in 2050, and the energy consumption will be 6.6%. Since waterways are generally an inconvenient form of passenger transportation and restricted by a wide range of conditions, their service level and energy consumption will be very limited. As for the energy mix in intercity passenger transportation, aviation kerosene and diesel are the main fuel categories. Aviation kerosene will account for 55% of intercity passenger transportation energy consumption in 2050 due to greater popularity of civil aviation. Diesel is mainly used by intercity buses and will account for 31% of the intercity passenger transportation energy consumption in 2050, a slight decline from the level in 2010. Natural gas is an important clean alternative vehicle fuel. Compared with the base year, the shares of electric power, LPG and gasoline will not change much.

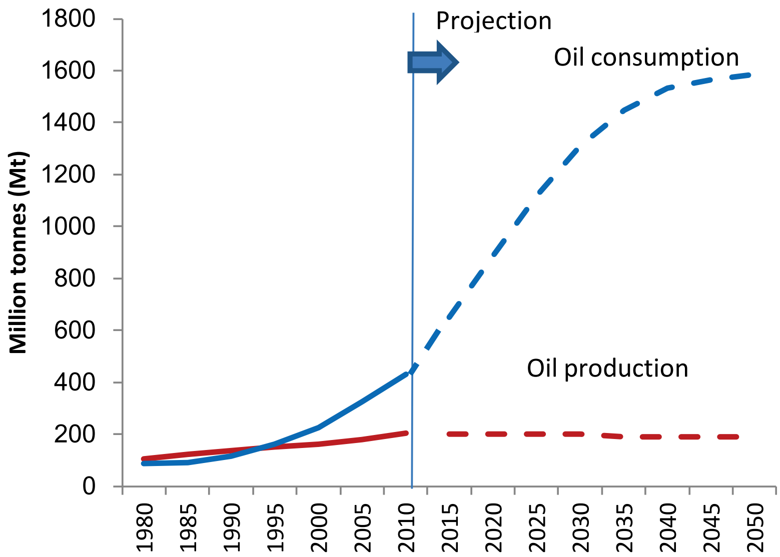
The energy consumption of urban passenger transportation will peak in 2040. As the urbanization process accelerates, the population living in cities will increase yearly, but the growth rate will significantly slow down after the urban populations reaches 980 million by 2030. Affected by urbanization, improvements in urban passenger transportation and progress in technical efficiency, urban passenger transportation energy consumption will peak in 2040 at 310 Mtce. The main factors behind the peaking are the stability of the urban population size and the gradual saturation in urban mobility needs. Compared to the level in developed countries, China still has some space to further improve the model structure of its urban passenger transportation structure, but the energy consumption of its urban passenger transportation is expected to peak before 2050. From the perspective of the energy mix of urban passengers, gasoline is the main fuel for urban passenger transportation energy consumption. In 2050, gasoline is projected to account for 76% of urban passenger transportation energy consumption, mainly because of its use as fuel for small private cars. The penetration rate of electric vehicles will be approximately 30% of private vehicles and taxis, but the proportion of their energy consumption will be limited, approximately 9% of the total energy consumption of urban passenger transport. Natural gas, ethanol and diesel will be used as fuel for taxis and buses, and the change will be moderate compared with that in the base year.

Rapid growth in the energy consumption of transportation imposes challenges for sustainable transportation development

Rapid growth in demand creates huge pressure for energy safety. The energy consumption in the transportation sector is mainly in the form of petroleum. In the Reference Scenario, oil product consumption will reach 1.09 Gtce, and its share in the final traffic energy mix in 2050 will rise to 81% (see Figure 5-5). If the proportion of oil consumption in the transportation sector in the whole of society remains unchanged, then due to the limited space for further increase in domestic oil production, the gap between supply and demand can only be satisfied through imports. China's dependence rate on oil import will gradually increase from 59.5% in 2014 to 88.0% in 2050.[13] This is 20% higher than the record high oil import dependence rate of 67% in the history of the United States, and

13 It is assumed conservatively that oil product consumption in other sectors remains unchanged based on 2010.

FIGURE 5-5. Historical trends and projections of future oil production and consumption



will bring in high risks and uncertainties to China's geopolitical position. Along with the rise in the dependence rate on oil import, fluctuations in international energy prices will hugely influence China's domestic economic activities. Oil products, as the main fuel in the transportation sector, are an important component of overall production costs. Rises in oil prices will cause higher costs of the transportation and increases in the costs of private vehicle trips. These influences will be transmitted through supply chain and create a risk of inflation for the whole of society.

Transportation-related emissions will exacerbate environmental and climate change problems. Today, China faces severe environmental problems. Each year, the Beijing-Tianjin-Hebei region, the Yangtze River Delta, and the Pearl River Delta are covered in heavy smog for more than one hundred days, affecting a population of approximately 600 million. In some cities, the number of days with heavy smog even exceeds 200. One important factor behind the bad smog pollution is the pollutant emissions from the use of motor vehicles. NO_X emissions mainly come from motor vehicles, power plants and industrial combustion. At least 74% of the near-surface NO_x concentrations are from motor vehicles. Motor vehicle emissions are close to the ground and lower than the emissions from other sources, thus making it the main source of near-surface NO_x concentrations. The PM2.5 content of motor vehicle emissions is also high, but the sources of PM2.5 pollution are diversified and the mechanism of its formation is complicated. In addition to direct emissions, PM2.5 pollution also stems from physical and chemical processes occurring in the atmosphere. Its chemical composition is complicated and includes a variety of organic compounds. More than 50% of the PM2.5 contents are the products of various physical and chemical processes in air and PM2.5 is a typical secondary pollutant. The Paris Agreement adopted at the International Conference on Climate Change in 2015 is the latest treaty of the international community to jointly address climate change. It reflects the decision and will of all countries around the world to promote green and low-carbon development, and to make efforts to control global average temperatures to within 2°C compared with the level before industrialization and to strive to control the temperature rise within 1.5°C. The transportation sector, as the important sector for carbon emissions, should also make a contribution to global carbon emissions reduction.

The existing development trend in transportation makes improvements in living quality weak. During the past decade, urbanization in China has been developing at twice the world average rate. The problems caused by unplanned urban sprawl are gradually noticeable. Irrational land use, huge infrastructural investment, increases in private car ownership, bad traffic congestion during rush hours, and low utilization rates of urban roads and municipal resources are causing a decline in the quality of urban life. Urban residents spend long time commuting and suffering from various environmental problems in cities. Urban sprawl increases the share of trips by private vehicles. Private vehicles can improve access but have high external costs in three aspects. The first external cost is related to various impacts during vehicle uses, including air pollution, noise, water and soil pollution, and traffic accidents; the second externality related to vehicle life cycle when cars are not running on road, including the pollution caused by vehicle production and disposal, land

occupation for parking, and congestion in parking zones. The last externality is closely related to transportation infrastructure, including damage to urban landscape, the barrier isolation effects on community life and the separation effect on ecological environment.

In summary, in the Reference Scenario, if the transportation sector continues the existing development trends, energy consumption will double by 2050, presenting severe challenges to national oil security. At the same time, it may trigger various environmental problems in urban areas and climate change, impeding the country's pursuit for sustainable development. Therefore, development of the transportation sector must be reshaped to save energy and to change existing sustainable development modes and trends.

Changing the energy-use mode under the Intensified Energy Conservation Scenario can realize multiple effects of energy conservation and energy diversification

In the Energy Conservation Intensification Scenario, by reducing and adjusting transportation service demand, optimizing and changing the structure of transportation services, speeding up the switch to clean fuels and significantly improving the energy efficiency level of transportation devices, final energy demand in the transportation sector in 2050 will be reduced from 1.35 Gtce to 686 Mtce. The diversification of transportation energy mix and the shift to clean processes will be significantly accelerated and the energy demand and carbon emissions of the transportation sector will peak around 2035 (see Figure 5-6).

In the IEC Scenario, China will move towards an urbanization model in which large, medium and small cities develop in a harmonious manner. The dominant role of energy intensive industries will be replaced by a combination of a service sector and high value-added industry. The internal space layout of cities, assisted by information and communication technologies, can effectively reduce trips and improve the efficiency of transportation systems. In the IEC Scenario, the vision of constructing high-efficiency, clean, green, low-carbon, convenient and comfortable transportation systems will be realized; transportation energy consumption, economic and social progress and the environment will be decoupled; and the transportation sector will be on the track of sustainable development.

Under the IEC Scenario, great efforts will be made to support low-carbon development of the transportation sector, to meet the country's transportation service demands, and to realize the decoupling of transportation development from energy demand growth. China will opt for a brand new industrialization pathway, adopt the urbanization mode of coordinated development, optimize transportation organization and management with advanced technologies, and make efforts to improve the energy efficiency of transportation devices. In the IEC Scenario, despite slow growth in transportation energy consumption, the transportation sector will be able meet the national economic and social development's demands for transportation services. Compared with 2010, the transportation sector's final energy demand will peak around 2035 and decline thereafter. By 2050, the trans-

FIGURE 5-6. Energy conservation potential and pathways in the IEC scenario

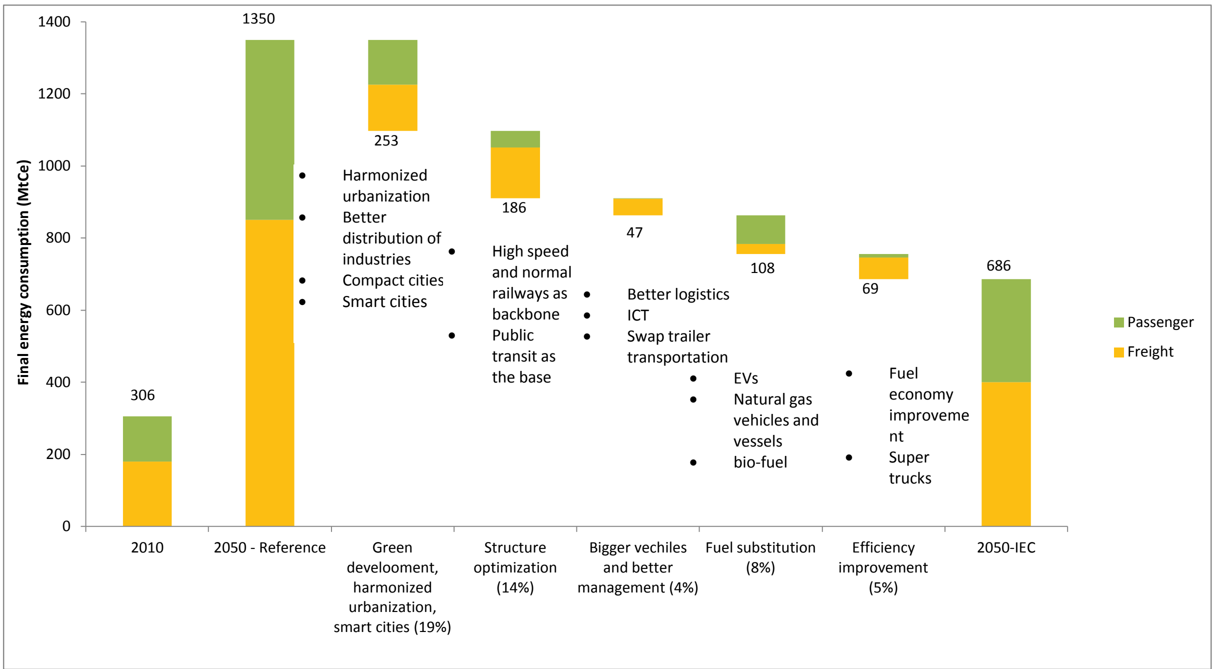
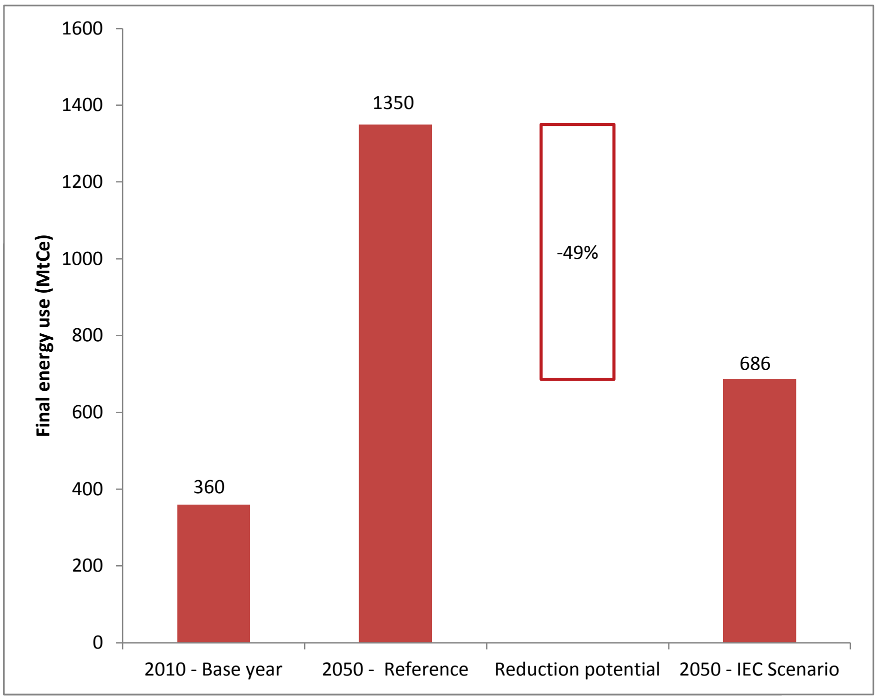


FIGURE 5-7. Final energy demand of the transportation sector under different scenarios



portation sector's energy demand will be only 686 Mtce; the annual growth rate of the final energy demand for transportation during 2010-2050 will be 2.0%, just 0.42% of the annual GDP growth rate in the same period. Compared with the Reference Scenario, the final energy demand for transportation in 2050 under the IEC Scenario will be around half (see Figure 5-7), realizing the decoupling of transportation development and energy demand increase.

Under the IEC Scenario, the transport sector will provide convenient and quick transportation services with high energy efficiency, clean and diversified modes of transportation, while its consumption of fossil fuel will not see major increases. China will vigorously develop alternative fuels and continuously improve the fuel economy of vehicles. Future transportation energy demand will see slow growth rates, and the energy mix will be significantly improved. Figure 5-8a shows the fuel mixes of the transportation sector under the two scenarios. Under the IEC Scenario, biofuel, natural gas and electric power will become the fast growing fuel types in future traffic energy consumption and electric will become the second major fuel type, and natural gas the third one. During the modeling period, the annual growth rate of diesel oil demand will be only 0.6%. The demand for diesel in 2050 will be 187 Mtce, an increase of just 20% from the level in 2010. Along with significant improvements in the efficiency of conventional gasoline vehicles and the development of alternative fuels, gasoline demand in 2050 will be only 48.64 Mtce, 50.9% less than the level in 2010. Aviation kerosene demand will maintain a growth rate of 2.9% during the 2010-2050 period.

Under the IEC Scenario, the government will focus on model innovation and technical progress for early carbon emissions peaking and realize the decoupling between transportation development and carbon emissions. In the IEC Scenario, in the future fossil fuel consumption of the transportation sector will see slower growth. By 2050, the petroleum demand in the transportation sector will be only 230 Mt, increasing by just 14% from the level in 2010, and just 31% of the petroleum demand in the Reference Scenario at that time (see Figure 5-8b and Figure 5-9), and it will peak around 2035 at approximately 390 Mt (550 Mtce). By 2035, the final energy demand of transportation will peak at 720 Mtce. Carbon emissions will reach 1.43 Gt in 2035 but only 1.23 Gt in 2050, thus realizing the decoupling between transportation development and carbon emissions.

Under the IEC Scenario, the transportation sector will see constant energy efficiency improvement; its pollutant emissions will be significantly reduced; and urban environment and transportation service quality will see remarkable improvement. Such energy efficient transportation modes as railways and waterways will see their declining shares in the transportation services reversed. Along with intelligent transportation system development in urban passenger transportation, public transit will experience constant improvement in its service

FIGURE 5-8a. Fuel mix of China's transportation sector

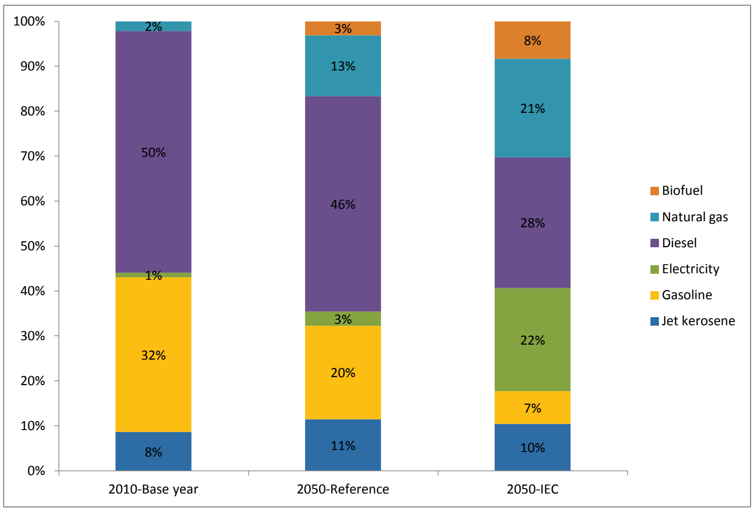
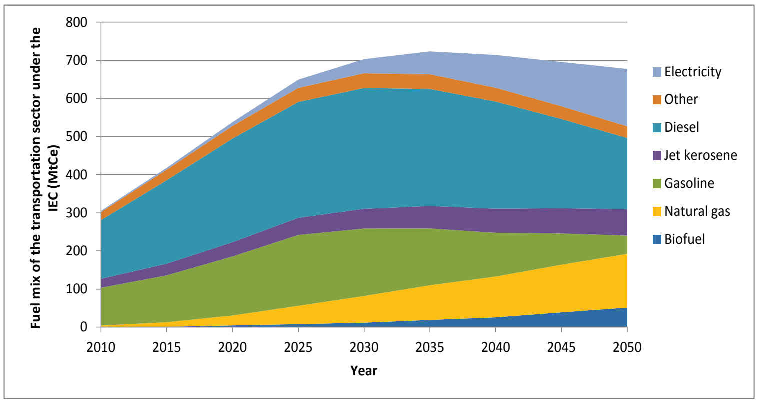


FIGURE 5-8b. Final energy demand and fuel mix under the IEC Scenario



quality and a constant increase in its share in the urban transportation services. At the same time, along with technical advances, the energy efficiency of different means of transportation such as the railways, roads, waterways, and civil aviation will be remarkably improved, and the transportation sector's overall energy efficiency level will remarkably higher (see Figure 5-10). Compared with 2010, the energy consumption per 10,000 km will be 0.09 tce by 2050, approximately 40% lower; the energy intensity of the transportation sector in terms of its GDP contribution will be reduced by more than 60%.

FIGURE 5-9. Final energy demand and carbon emissions in the transportation sector under the IEC scenario

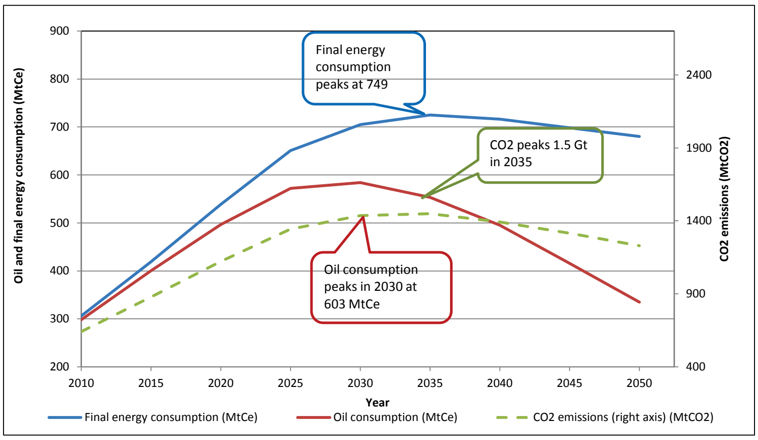
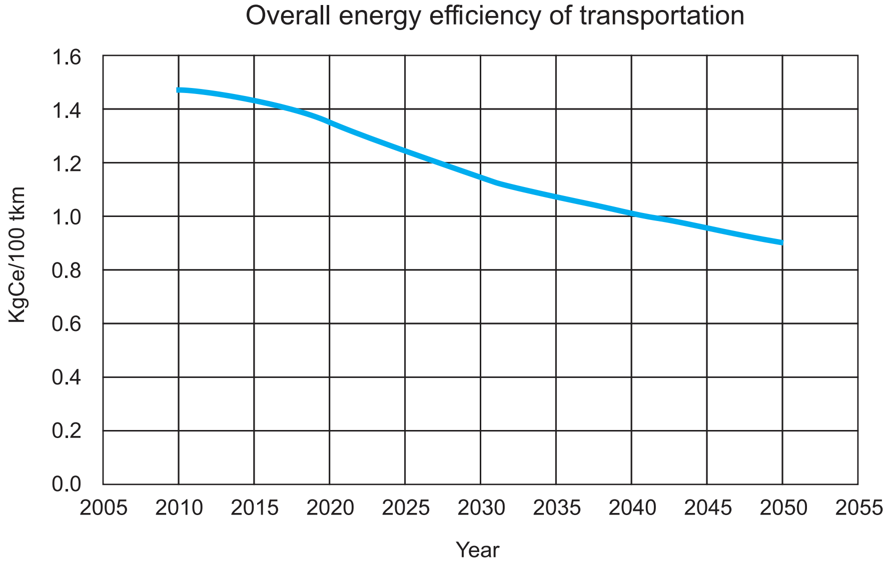


FIGURE 5-10. Overall energy efficiency evolution of the transportation sector under the IEC Scenario



5.3 IDENTIFICATION OF HIOS IN THE TRANSPORTATION SECTOR IN CHINA

The energy efficiency improvement potential lies in both transportation mode changes and efficiency improvements to vehicles. The following is an analysis on the high impact opportunities for energy-efficient technologies and structural optimization in the transportation sector under the IEC Scenario. This is followed by discussions on the main barriers and some recommendations on how to overcome them.

5.3.1 TECHNICAL HIOS

HIO 1: Improve the fuel economy of trucks

To improve the fuel economy of trucks, tighter standards for their fuel economy should be formulated. The key effective technologies in reducing fuel consumption per hundred kilometers by trucks include equipping trucks with an aerodynamic structure, use of low rolling resistance tires, tire pressure monitoring, improving the thermal efficiency of engine, pressure recovery and electrification accessory appliances such as pumps and air-conditioning. To improve the fuel efficiency of on-road trucks, the problem of frequent severe overloading of trucks shall be addressed and policies shall support the market shift to bigger trucks for freight transportation.

Through a package of energy efficiency improvement plans and policies for truck energy efficiency improvement, it is projected that by 2050, the fuel efficiency of China's truck fleet can be improved by 45%, increasing by 20 percentage points higher than the 25% efficiency improvement under the Reference Scenario. This can lead to an energy saving of 45.94 Mtce per year(see Figure 5-11).

The most cost-effective energy-saving opportunities lie in improvements to engine efficiency, aerodynamic improvements, and low rolling resistance tire technology. For the specific cost and energy conservation capacity of each technology, see Figure 5-12. While the price of diesel is kept at the level of RMB 7.76/L, except for hybrid power and vehicle weight reductions, all other energy-efficiency improvement technologies are cost-effective. To achieve the objective of improving the fuel economy of trucks by 45% (assuming the operation life of trucks is at seven years on average), about RMB 390 billion (at constant prices in 2010) of investments is needed to update truck-driving software, tire monitoring, the electrification of auxiliary functions and to improve engine efficiency, aerodynamic performance and the use of other technologies.

There exist some barriers to improvements to truck fuel economy. First, the fuel economy standards for trucks in China are not strict enough, and the enforcement rates of the standards are low. In the future, China needs to tighten the standards and improve the compliance rate of the standards. At present, overloading and empty trips of trucks in China is an extremely serious problem; they dramatically increase the actual fuel consumption levels of truck. The administration agencies for transportation should find a way to effectively eliminate the overloading of trucks and improve the safety of trucks during on-road running. The emissions of a truck are many times those of an ordinary light vehicle. To address the problem of air pollution, more restrictions shall be enacted on truck emissions in the future. This will also indirectly lead to fuel economy improvement of trucks. Another barrier

FIGURE 5-11. Energy-saving potential from inmproving truck fuel economy under the IEC Scenario compared to the Reference Scenario

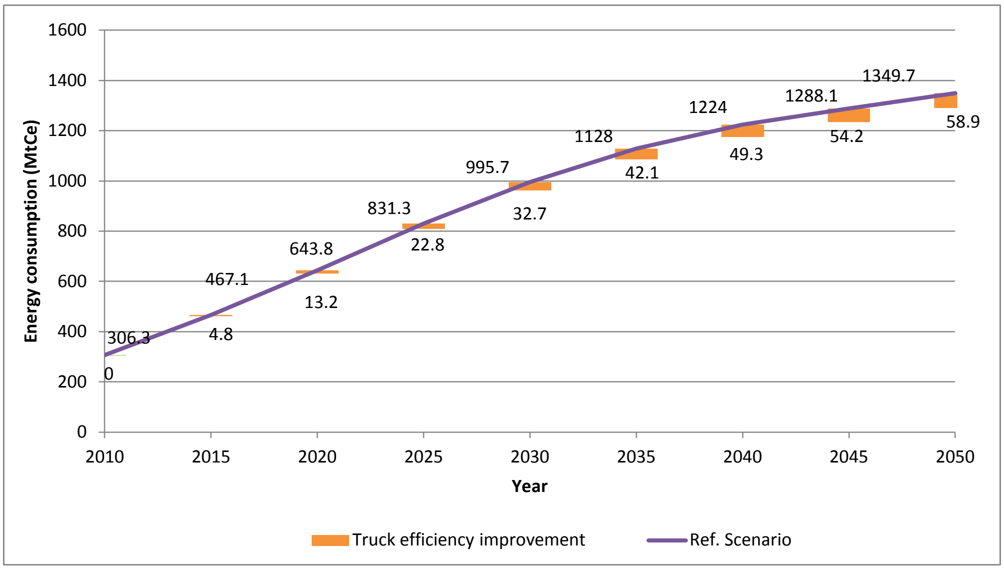
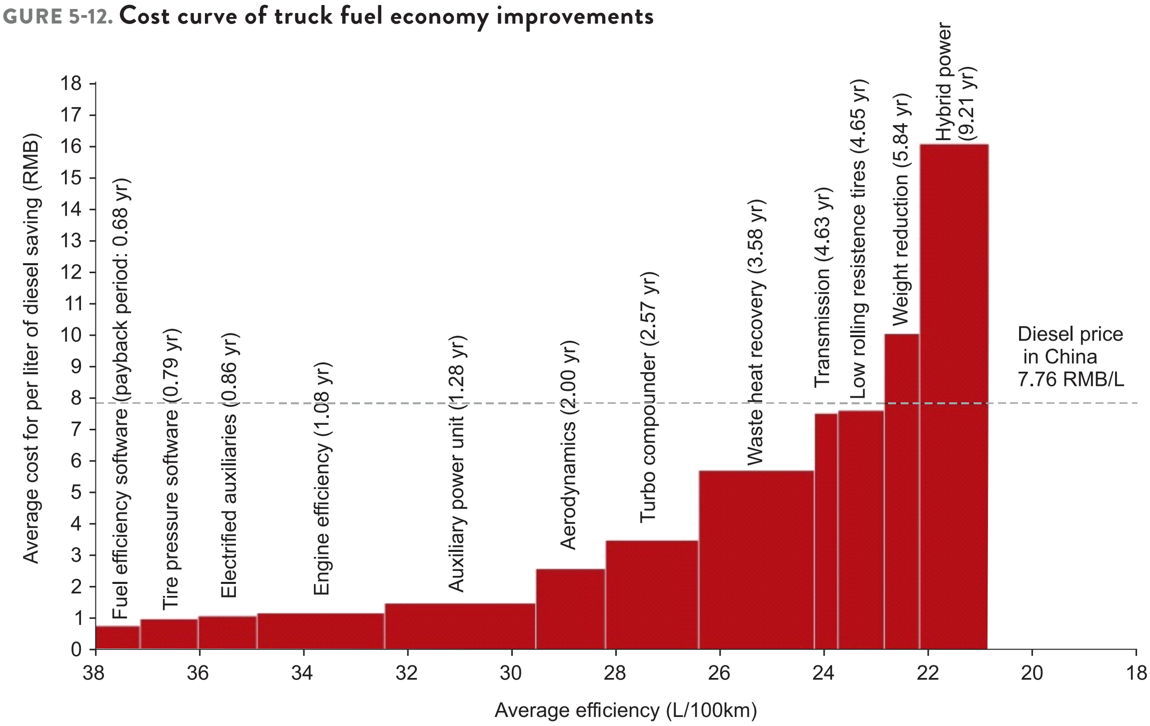


FIGURE 5-12. Cost curve of truck fuel economy improvements



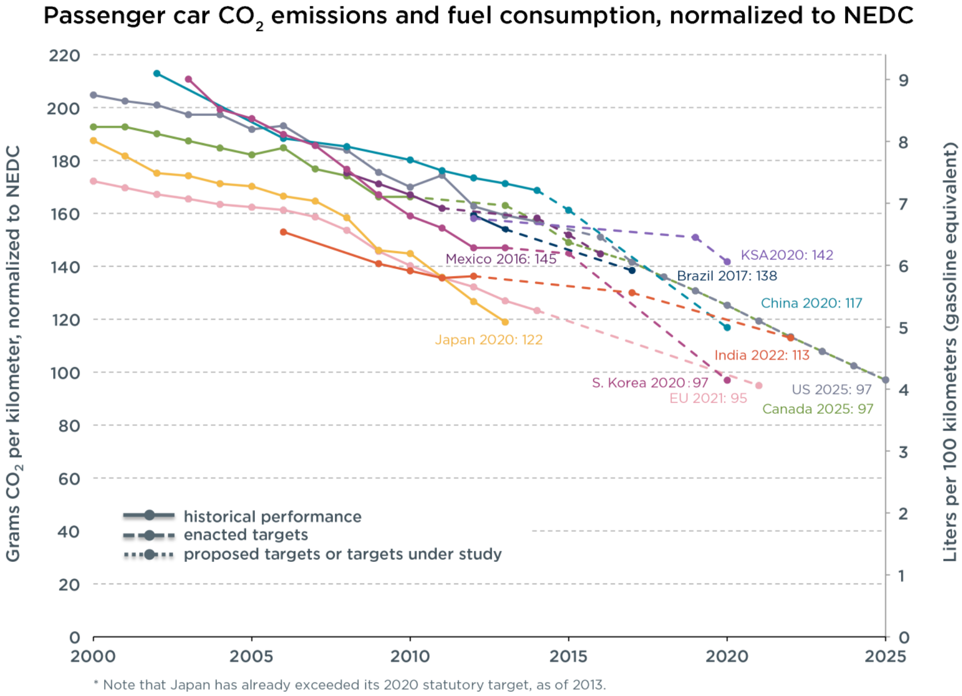
Source: Cost-benefit Analysis of the Reinventing Fire China Project

is that truck manufacturing enterprises attach little importance to energy conservation technologies, and their technical research and development capabilities are low. These are all important factors affecting the upgrading of truck fuel economy.

HIO 2: Improvements to the fuel economy of light passenger vehicles

Currently, China is implementing Phase IV of the *Standard for Fuel Consumption Limits of Light Passenger Vehicles*. The standard for the first three phases has played a very important role in promoting the fuel economy of light passenger vehicles in China. In the future, the mandatory

FIGURE 5-13. Improvement in fuel economy in various countries and outlook



Data source: ICCT, updated in September 2015

national standards will be continuously implemented as an important instrument for vehicle energy efficiency level improvements, reductions of urban pollution, and promoting sustainable development in transportation. According to the predictions of the International Energy Agency (IEA), the fuel economies of light vehicles will be significant improvement in all countries around the world in the future (for more details, see Figure 5-13).

Through the mass application of such new materials as carbon fiber, aluminum, high-strength steel and compound materials, light-duty vehicle will become lighter in weight. Through a package of technical improvements, including engine design optimization, improvements to vehicle drive systems, intelligent starting/stopping, energy recovery systems, aerodynamic performance improvements and frictional resistance reductions, the fuel efficiency of vehicles can be improved to 3 L/100km. This includes the contribution of battery electric vehicles and plug-in hybrid electric vehicles. For the entire fleet, compared with the base year of 2010, the energy consumption per vehicle·kilometer of taxis on the road can be reduced by 72%, and the energy consumption per vehicle·kilometer of private vehicles on the road can be reduced by 66% (see Figure 5-14).

FIGURE 5-14. Fuel economy improvement of the private vehicles and taxi fleets under the IEC Scenario

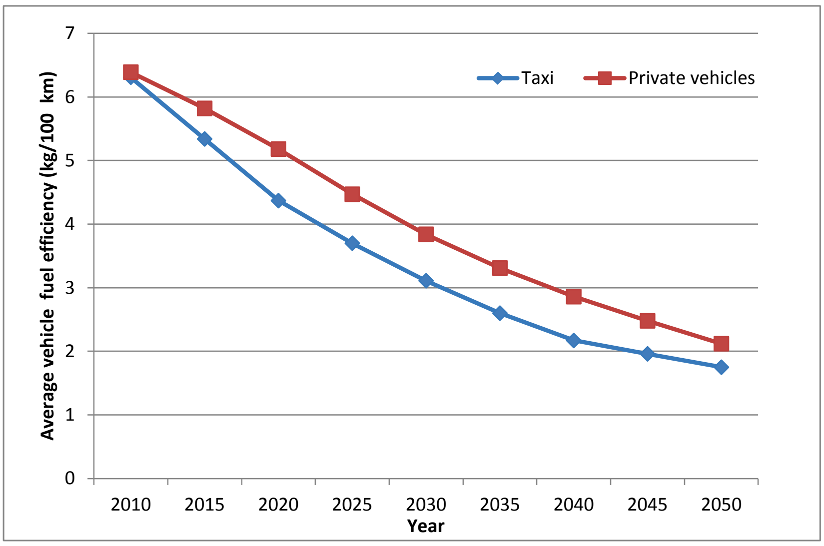
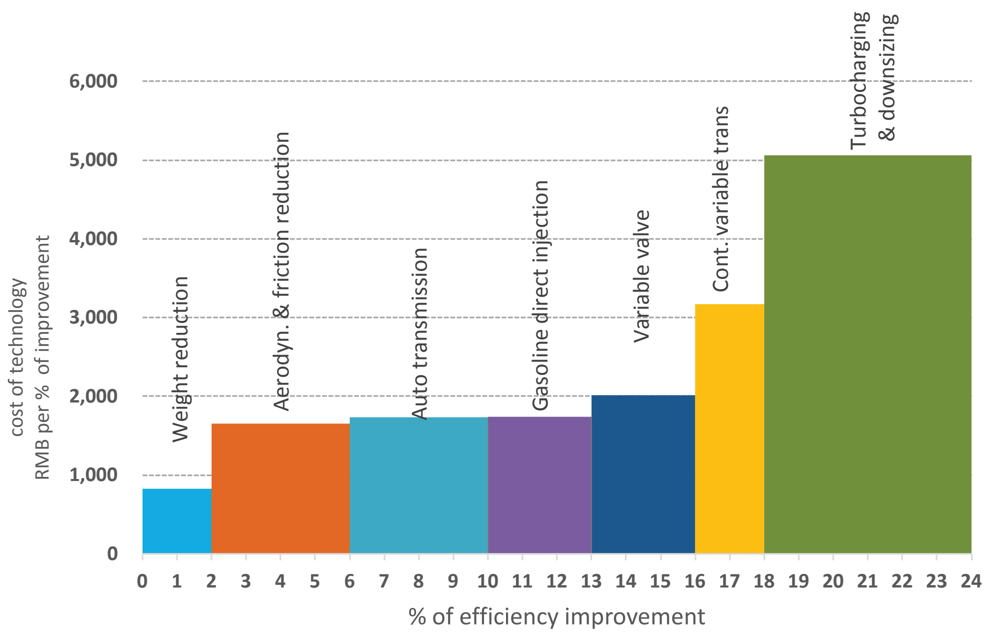


FIGURE 5-15. Cost curve for the fuel economy improvement of light duty vehicles



Source of Data: Richard A. S., et al., 2015

Apart from the technologies for improving the vehicle fuel economy of light passenger vehicles, switching from fossil fuel to various cleaner fuels can also bring about some efficiency improvements to light duty vehicles by 2050. For more detailed technologies and costs, see Figure 5-15.

HIO 3: Development and wide application of battery electric and plug-in hybrid electric vehicles

Electric vehicles (EV), as a promising solution for low-carbon transportation development, have now been rapidly developed in all countries around the world in recent years. China became the largest EV market in the world in 2015. The main driving forces behind this change in China are policy support and subsidies. Worldwide, the total number of EVs in use has exceeded 1 million. EVs mainly include battery electric vehicles (BEV) and plug-in hybrid electric vehicles (PHEV), as well as hydrogen fuel battery vehicles (HEV). BEVs are mainly driven by electric motors. The engine system of PHEVs consists of both an internal combustion engine and an electric motor, so it runs on both oil and electricity. The main fuel of HEVs is hydrogen. The process of vehicle hydrogenation is much faster than the electricity charging process, basically equivalent to the refueling speed of traditional vehicles based on internal combustion engines (ICE).

EVs are associated with high energy-saving potential. Compared with traditional ICE-based vehicles, they can be 35% more energy efficient. With renewable energy contributing an increasingly high share of grid electricity in the future, EVs can reduce emissions by approximately 20% during their whole life-cycle (towards 2020, the share of clean energy for the grid will be increased, but the coal-fired power generation will contribute the majority of grid power in China (Zhang et al 2013). The fuel economy of traditional ICE-based vehicles will continuously improve). In our analysis, private vehicle ownership in China in 2050 will be 440 million, taxi ownership 3.5 million, and privately owned buses 5 million. Almost all of these vehicles can be electric ones, including BEVs and PHEVs. More than 70% of urban buses will be EVs and play an important role in urban air pollution reduction. Through the substitution of EVs, by 2050, the Chinese transportation sector can achieve an energy saving of 49.22 Mtce (see Figure 5-16).

Compared with traditional ICE-based vehicles, EVs are more expensive and this remains true even if fuel consumption costs and maintenance costs are included. Australia's RACQ conducted a detailed market survey and analysis of the selling price of different types of vehicles, covering more than ninety vehicle models. Below is a comparison of the annualized average cost of conventional ICE-based vehicless, PHEVs and BEVs; the annualized cost includes the annual depreciation of vehicles, operating and maintenance costs, and fuel costs. It can be observed that currently, the annual operating costs of electric vehicles are nearly 30% higher than traditional ICE vehicles (see Figure 5-17).

FIGURE 5-16. Energy saving potential from replacing ICE-based vehicles with EVs in the IEC Scenario in comparison with the Reference Scenario

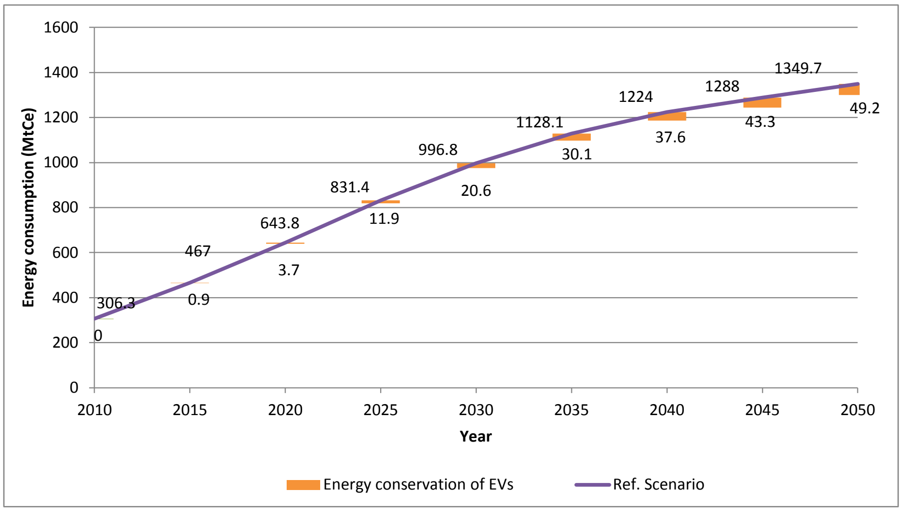
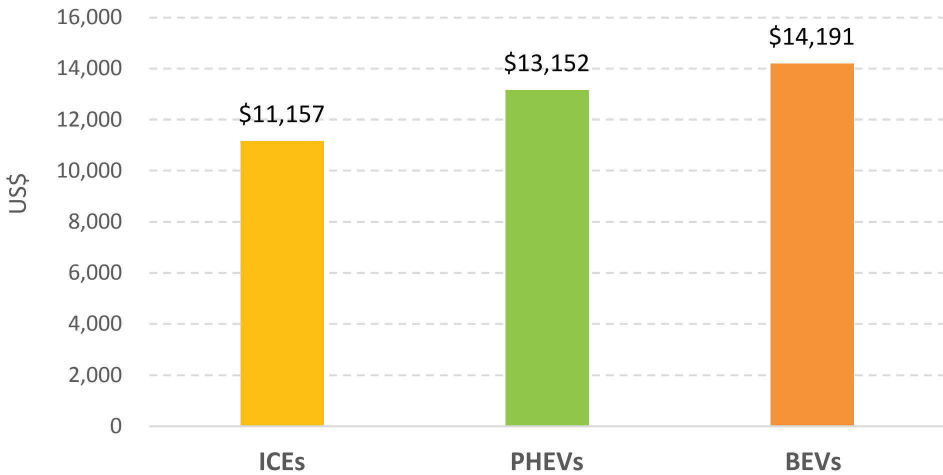


FIGURE 5-17. Comparison of annual costs among ICEs, PHEVs and BEVs



Source of data: RACQ Vehicle Running Costs 2014

Note: Annual cost includes purchase cost, operating and maintenance cost, fuel cost, etc. and the average value of the prices of different types of vehicles

There are some barriers to the wide application of electric vehicles. The first barrier is some technology problems in electric vehicle technology; particularly the battery technology is not mature yet. The second barrier is lack of infrastructural support and construction. The Chinese government has issued a *Development Guidance for the Construction of Charging Infrastructure of Electric Vehicles* (2015-2020), but in reality, there still exist problems in such aspects as high electricity prices, low capacity in the manufacturing of chargers, and difficulties in connections to the electricity grid.

HIO 4: Improve the electrification of the railways

Currently the locomotives used in the Chinese railway system are mainly the internal combustion locomotives and electric locomotives. Steam locomotives have already been replaced. Internal combustion locomotives and electric locomotives respectively accounted for 56% and 43% of the Chinese locomotive stock in 2010. The efficiency level of electric locomotives is about three times that of internal combustion locomotives. The electrification level of the railway system should be significantly improved to achieve higher efficiency level of the railway system and to promote switch to clean and modern fuel forms in railways.

In 2050, railways will contribute 40% of the passenger transportation turnover and 24% of the freight turnover respectively, making railways the backbone and main mode for long-distance transportation in China. The electrification and efficiency levels of the railway system have a significant influence on the energy mix of the entire transportation sector. For passenger transportation, the proportion of electric locomotives will gradually increase from less than 50% in 2010 to 100% in 2050. The proportion of electric freight locomotives will increase from less than 50% in 2010 to approximately 80% in 2050. The railway system will achieve electrification on the whole, thus realizing energy savings of 11.28 Mtce in 2050 (see Figure 5-18).

In terms of operating costs, the energy cost of electric locomotive traction is lower than that of internal combustion locomotive traction, which is mainly due to the price levels of electricity and diesel in China, as well as the higher efficiency of electric locomotives. Taking other operating costs into consideration, including the depreciation of fixed assets and O&M costs, the total operation cost of electric locomotives is also lower than that of internal combustion locomotives (Yu 2014).

The barriers to railway electrification. In recent years, railway electrification has been progressing steadily in China, especially since the rapid development of high-speed railways; and the speed of electrification has been accelerating. The service life of an internal combustion locomotive is approximately thirty years and when their service life ends, they will be replaced with electric locomotives.

5.3.2 STRUCTURAL HIOS

HIO 1: Increase the share of public transit

The efficiency of urban public transportation systems is much higher than that of driving private cars. The energy consumption of an urban trip by compact vehicle is three times higher than that by bus. By encouraging urban residents switch from using private cars to using public transport in the form of urban rail transit systems, BRTs, public service vehicles, the energy consumption of urban passenger transportation can be effectively reduced. Compared to main cities in developed countries, the share of urban public transit in China has enormous room of improvement. Beijing is a leading city in the development of public transit systems, but even in Beijing, public transit accounts for less than 50% of urban passenger transportation. Beijing still lags much behind Hong Kong, Singapore, and New York in public transport development, where the share of public transit in urban passenger transportation exceeds 70% (see Figure 5-19).

Measures to increase the popularity of urban public transit mainly include accelerating the construction of urban public transportation infrastructure, improving the accessibility of rail transit and public transportation, realizing zero-distance transfers between different modes of public transportation, adopting information technology to make urban public transit more convenient and quicker, increasing the costs of private vehicle uses through such measures as collecting parking charges and congestion charges. By 2050, all Chinese cities with a population

FIGURE 5-18. Energy-saving potential of railway electrification in the IEC Scenario compared with the Reference Scenario

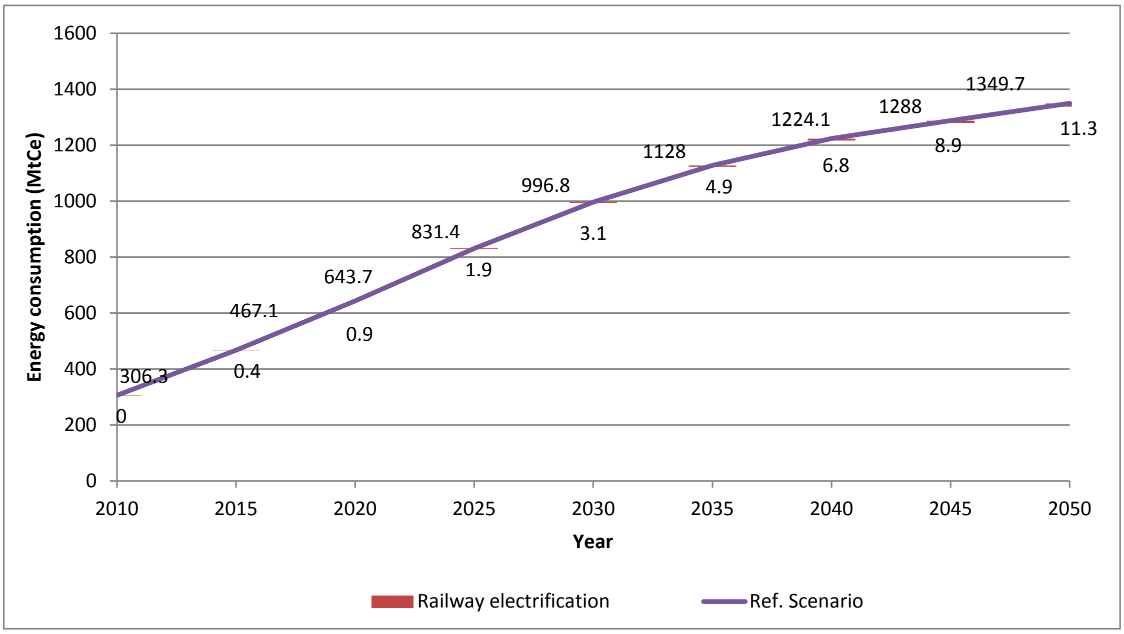
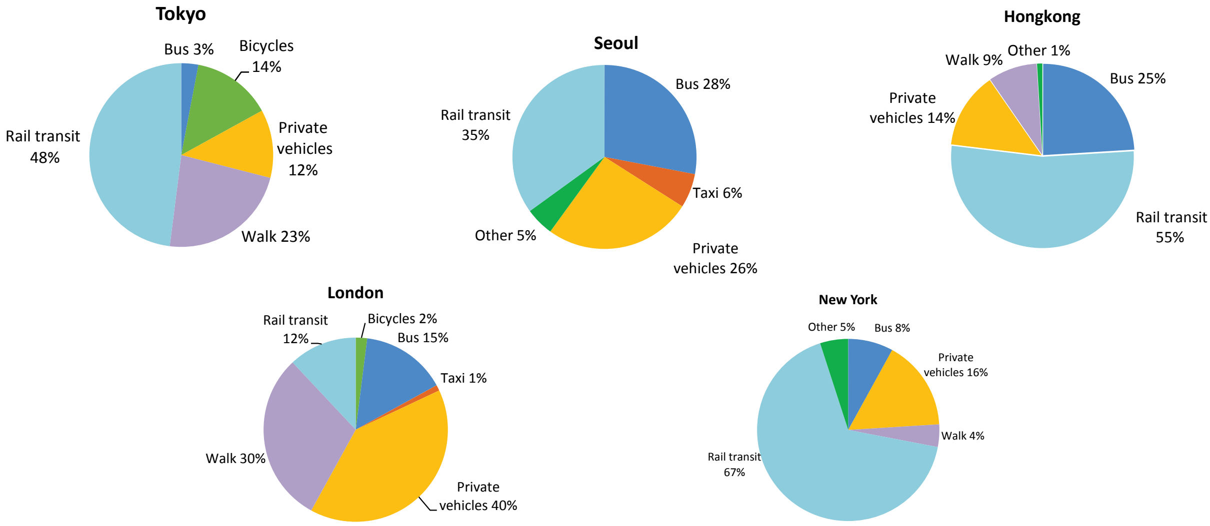


FIGURE 5-19. Share of trip modes in major cities in the world



of more than five million shall create an urban transport system dominated by rail transit and BRT systems. Cities with a population of more than 1 million will mainly focus on public transit, while small cities will focus on individual transportation. By 2050, metro trips will account for 20% of urban passenger transportation. At that time, the share of travel by public transit systems will reach 64%. This transformation in urban transportation can create 14.85 Mtce of energy savings.

The barriers to increasing the share of urban public transit mainly include poor urban planning, the constant expansion of megacities, the function specialization of different city areas as residential areas and office areas, and the huge traffic in rush hours and long commuting distances, which make public transit an unfavorable option for passenger transportation. Also the construction of public transit systems needs huge investment and the upfront investment is high. Improvements to comfort levels also need funding and may increase energy consumption. Finally there is also the consumer behavior barrier to which can also affects the share of public transit in urban transportation.

HIO 2: Increase the share of railways

The energy consumption of high-speed railways per passenger·km is only 1/5-1/3 that of aviation. For trips shorter than 1,000 km, high-speed railway is both cheaper and faster than aviation. Meanwhile, with passenger transportation shifting from ordinary railways to high-speed railways, more railway transportation capacity can be made available for freight transportation. This can not only replace long-distance road transportation, but also improve the energy efficiency of freight transport.

Today the total length of high-speed railways in China has reached 16,000 km, representing more than 60% of the global mileage of high-speed railways. China plans to build another 45,000 km of high-speed railways, bringing its total railway mileage to 200,000 km. The high-speed railway networks will connect all provincial capitals and other large and medium-sized cities with a population of more than 500,000. At that time, the 1-4 hour traffic circle will be realized for adjacent large and medium-sized cities. An intercity passenger transportation system with high-speed railways and railways as the framework will come into being, enabling railway to play a key role in long-distance passenger and freight transportation.

Currently, the main barrier to enlarging the share of railway trips is insufficient capacity of high-speed railways and ordinary railways. In the future, the connections between high-speed railway stations and cities will be the most important factor affecting the popularity of high-speed railways. Therefore, attention should be paid to improving the connections between high-speed railway stations and urban public transit facilities.

HIO 3: Vehicle sharing

Vehicle sharing has been spreading around the world at an amazing speed in recent years. Not only each vehicle is shared and used by different people at different times, but also several passengers can take the same vehicle during a trip to one or more destinations. Vehicle sharing not only means faster and more convenient trips, but also higher energy efficiency. Digital platforms can enable more passengers to share vehicles and reduce future private car ownership. Vehicle sharing, as the business model of a transportation service, combined with self-driving vehicles, electric vehicles and other new technologies, is dramatically changing the landscape of passenger trans-

portation. Since vehicle sharing can reduce vehicle depreciation, repair and maintenance costs for vehicle owners and users, it can also reduce transportation costs.

There are a few barriers to the dissemination of vehicle sharing. One major barrier to the uptake of vehicle-sharing is the traditional perception that considers car ownership a symbol of high social status and financial success. Some gaps in the regulatory system, such as relevant laws and regulations, insurance, information, are also important barriers.

5.4 POLICY RECOMMENDATIONS

5.4.1 RECOMMENDATION 1: BOOSTING THE REFORM AND UPGRADE OF TRANSPORTATION SECTOR GOVERNANCE

The government needs to end the phenomenon of multiple-authorities in charge of transportation sector governance in China, centralize the transportation administration into one government agency, make administration innovations, promote new business modes such as vehicle sharing, and attach importance to improve the connections between different transportation modes. It is also important to liberalize fuel-oil pricing and allow market supply and demand to play a bigger role in market price shaping, include environmental impacts in the market prices, and guide consumers to opt for clean and efficient transportation mode. China also needs to eliminate the institutional, standard and administrative barriers to connecting different transportation modes, implement container standardization, and attach importance to the seamless connection in infrastructure design and construction. The country needs to build a multimodal transport system that can exert the advantages of railways and waterways in long-distance transportation and the flexibility of road transport in short-distance transportation; and it is also key to increase the proportion in logistics transport.

5.4.2 RECOMMENDATION 2: SPEED UP OF MARKET-ORIENTED REFORM OF RAILWAY TRANSPORT

It is important to take the following measures: breaking the monopoly of the railways, accelerating market-oriented railway reform, implementing floating pricing, allowing private capital access, eradicating institutional barriers to better connections between the railways and other modes of transportation. These measures can make it easier to mobilize private funding for the construction and operation of railways and high-speed railways, speed up the construction of a national network of high-speed railways and railways, boost the transformation and upgrading of ordinary railways, makes available more ordinary railway transportation capacity for the long distance freight transport, help improve operating efficiencies of railway transport. Declines in the share of railway in freight transport shall be reversed by 2022, and thereafter the share of railway in freight transport shall be increased to one quarter by 2050. The major cities will be connected by a network of high-speed railways, which will become the main mode of intercity passenger transport.

5.4.3 RECOMMENDATION 3: REGULARLY AND TIMELY RELEASE AND UPDATE FUEL ECONOMY STANDARDS

It is necessary for China to set and issue footprint-based fuel economy standards for vehicles and update the standards regularly, tighten the fuel economy standards for trucks, reinforce supervision and inspection, and reduce the difference between nominal fuel efficiency levels and actual operating fuel efficiency levels. Through offering preferential vehicle sales tax, the government can encourage households to buy and use small and more energy efficient cars. Through imposing heavy taxes, the government can discourage the ownership and use of high-emission and luxury vehicles.

5.4.4 RECOMMENDATION 4: EXPEDITE THE CONSTRUCTION, INVESTMENT AND FINANCING OF PUBLIC TRANSPORTATION INFRASTRUCTURE

In urban planning, transit-oriented development (TOD) should be taken as a priority. Residential blocks shall be built near the main public transportation corridor (metro + BRT), thus creating urban designing with public transportation as the main backbone. More emphasis shall be given to the construction of infrastructure for non-motorized transport; more investment shall channeled to building pedestrian lanes and bicycle lanes; congestion charging and parking charging in urban central zones should be reformed and increased, making it more expensive to use private vehicles in downtown areas; the share of private vehicle transport should be reduced. Governments at all levels shall continuously increase funding for the construction of urban public transit infrastructure, especially the construction of rail-transit facilities, attach importance to the construction of zero-distance transfer stations, improve the comfort level, speed, and reliability of public transportation. Public parking areas will be established in some transition stations to facilitate transfers between private vehicles and public transportation.

4.5 RECOMMENDATION 5: CONTINUE RESEARCH AND DEVELOPMENT AND TO PROMOTE ADVANCED TRANSPORT TECHNOLOGIES

China should intensify the research and development of EVs, achieve technical breakthroughs in battery life and mileage, service life, reliability, grid energy storage, etc., improve the utilization of the subsidy fund for EVs, avoid local protectionism, and attach equal concern and importance to PHEVs and traditional ICEs. The government can pilot the use of EVs as taxi and buses with preferential policies. The pilot results should be analyzed timely and used as inputs for further policy making. The government should speed up the planning and building of charging stations, achieve matching and coordinated development between grid load management and the electricity demand for EV charging, and uses EVs as an important solution for electricity storage and integrating more electricity from renewable sources.

REFERENCES

Huanjun Yu, 2014, A Study on the Operating Costs of Railway Electric Locomotive Traction, master's degree thesis

Xiliang Zhang, Xu Zhang, Xunmin Ou, China New-energy Automobile Industry Development Status and Prospect. *Environmental Protection*, 2013 (41), 10: 24-28.

CHAPTER 6

ENERGY EFFICIENCY POLICY AND HIGH IMPACT OPPORTUNITIES IN THE POWER SECTOR IN CHINA

Qingbing PEI
Quan BAI

6.1 REVIEW OF ACHIEVEMENTS AND POLICIES REGARDING ENERGY-EFFICIENCY IMPROVEMENTS TO POWER GENERATION IN CHINA

The power industry is an important foundation for national economic development and plays a very important role in both it and social progress. Then power industry is important not only for national economy security, but also for people's daily lives and social stability. Since the reform and opening up, along with the rapid development of China's economy, China's power industry has consistently been in a phase of high-speed development dominated by coal-fired power generation.

6.1.1 ACHIEVEMENTS IN ENERGY EFFICIENCY IMPROVEMENTS IN POWER GENERATION

Scale of power generation rapidly expanded

The scale of the power industry is expanding. In 1949, installed power generation capacity in China was only 1.84 GW and annual power output only 4.3 billion kWh (excluding Taiwan, Hong Kong, and Macao), ranking China 21st and 25th in the world respectively. In 1987 installed power generation capacity exceeded 100 GW, and China became one of the few countries with an installed capacity exceeding this figure. Since 2000, as the growth rate of China's economy has accelerated, China's power industry has also taken to the development speedway. In 2015, installed capacity reached 1508 GW, ranking the country first in the world (for variations in the installed capacity of the power sector in China since 2000, see Figure 6-1).

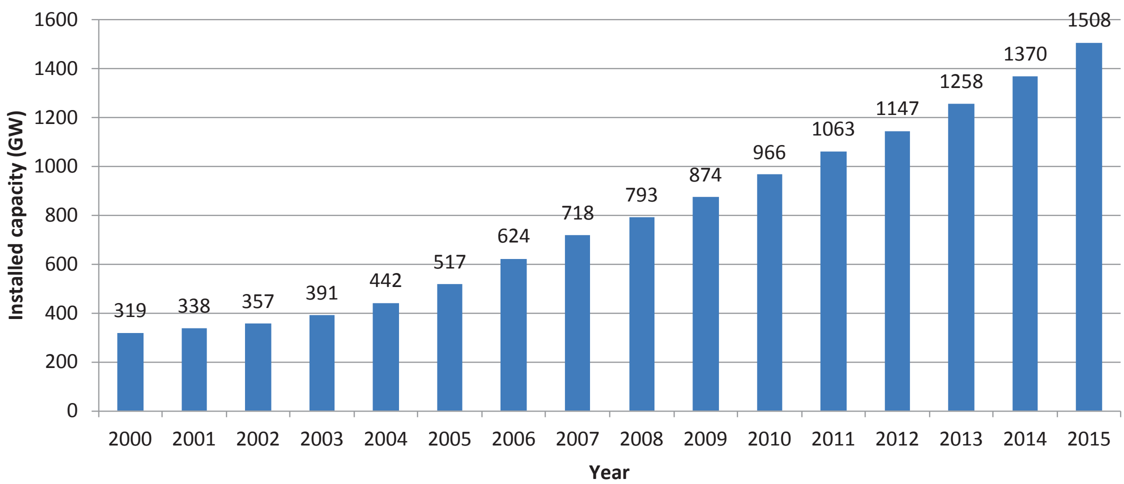
The rapid increase in installed capacity in China not only exceeds the country's own historical level, but is also is surprising compared with that of developed countries. Average annual newly installed capacity during 2005-2015 in China was 99.1 GW. This means that every week 1.5 power plants with a capacity of 1 GW were added, or every year an installed capacity equivalent to that of Britain (for a comparison with other countries, see Figure 6-2). Such a growth rate has rarely been seen in the world.

Power consumption obviously improved

In the wake of the rapid development of the economy, society and the power industry, both power generation and per capita power consumption are increasing rapidly in China. From 2005 to 2015, China's power generation increased from 2.49 trillion kWh to 5.81 trillion kWh at an annual growth rate of 8.83%, and per capita power consumption increased from 1907 kWh in 2005 to 4227 kWh in 2015 at an annual growth rate of 8.28% (see Table 6-1). This reflects the improvements in economic development and people's living standards in China.

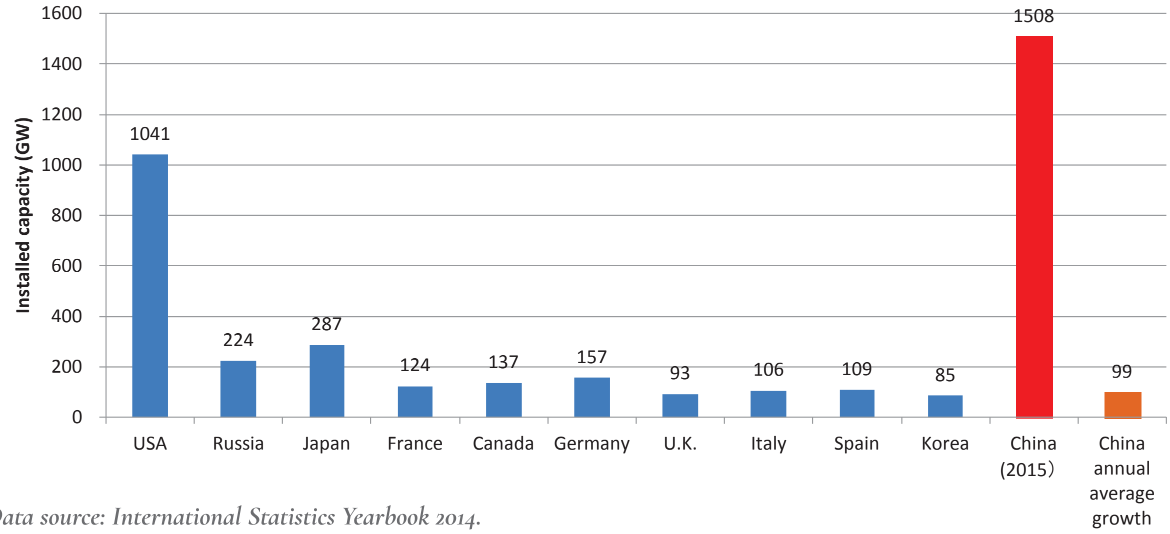
Compared with developed countries, however, per capita power consumption in China remains very low. The per capita installed power-generation capacity in developed countries is above 1.5 kWh and per capita power consumption mostly above 5000 kWh. Per capita power consumption in the USA and South Korea even reaches approximately 10,000 kWh (see Figure 4-3). China therefore still has a long way to go in industrializing and modernizing.

FIGURE 6-1. Installed power generation capacity in China since 2000



Data source: China Electric Power Yearbook 2001-2016

FIGURE 6-2. Installed capacity in China (in 2015) and some developed countries (in 2010)



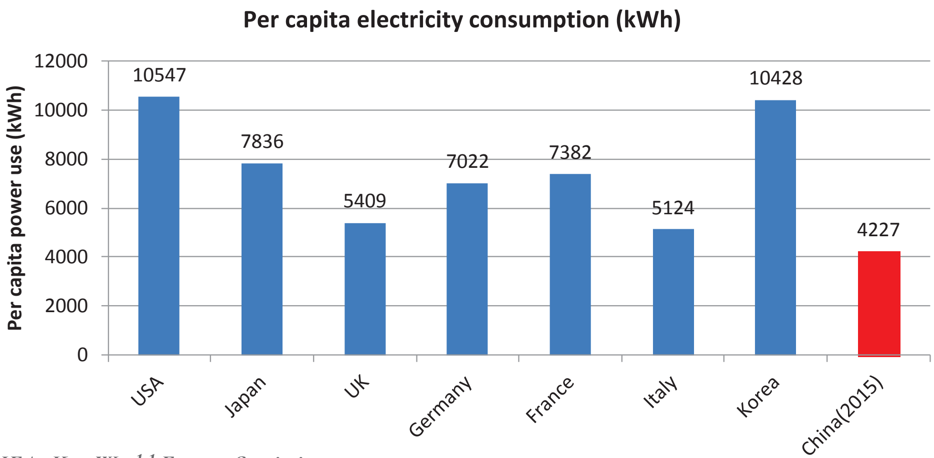
Data source: International Statistics Yearbook 2014.

TABLE 6-1. Power generation and per capita power consumption in China

	2005	2010	2011	2012	2013	2014	2015
Power generation (100 GWh)	24,940	41,934	47,001	49,763	54,203	56,384	58,106
Per capita power consumption (kWh)	1,907	3,127	3,488	3,675	3,983	4,122	4,227

Data source: China Energy Yearbook

FIGURE 6-3. Per capita power consumption in China (in 2015) and some developed countries (in 2013)



Data source: IEA, Key World Energy Statistics 2014

A power generation structure dominated by coal

The installed capacity structure in China has been dominated by thermal power all along, that is, on coal-fired power. In 2014, the installed capacity of thermal power in China was 920 GW, accounting for 67.4%, of hydropower 300 GW, accounting for 22.2%, of nuclear power 20.08 GW, accounting for 1.5%, of wind power 96.57 GW, accounting for 7.0%, and of grid-connected solar power 24.86 GW, accounting for 1.8% (see Table 6-2). Although the share of thermal power declined from 75.7% in 2005 to 67.4% in 2014, it still has the dominant position, with coal-fired plants accounting for more than 95%.

TABLE 6-2. Installed capacity of power generation from various sources in China and share changes since 2005

INSTALLED CAPACITY (10,000KW)	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Total installed capacity	51,675	62,342	71,745	79,284	87,433	96,699	106,305	114,617	12,5768	13,7018
Thermal power	39,138	48,405	55,607	60,286	65,108	70,967	76,834	81,968	87,009	92,363
Hydropower	11,739	12,857	14,823	17,260	19,629	21,606	23,298	24,947	28,044	30,486
Nuclear power	685	885	885	885	908	1,082	1,257	1,257	1,466	2,008
Wind power	106	187	420	839	1,760	2,958	4,623	6,083	7,652	9,657
Solar energy	7	8	10	14	28	86	293	341	1,589	2,486
Others								20	8	19
Share (%)	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Thermal power	75.7	77.6	77.5	76.0	74.5	73.4	72.3	71.5	69.2	67.4
Hydropower	22.7	20.6	20.7	21.8	22.5	22.3	21.9	21.8	22.3	22.2
Nuclear power	1.3	1.4	1.2	1.1	1.0	1.1	1.2	1.1	1.2	1.5
Wind power	0.2	0.3	0.6	1.1	2.0	3.1	4.3	5.3	6.1	7.0
Solar energy	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.3	1.3	1.8
Others	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Source: China Electric Power Yearbook 2006-2015

From the perspective of the output structure, the share of thermal power declined from 82.0% in 2005 to 75.4% in 2014; the share of hydropower generation capacity increased from 15.9% in 2005 to 18.9% in 2014; the share of nuclear power generation capacity fluctuated at around 2%; the share of wind power generation capacity increased from 0% in 2005 to 2.9% in 2014; and the contribution of solar energy appears to have been progressive (see Table 6-3). The share of clean energy therefore increased gradually.

The efficiency of the power sector continuously improved

The energy utilization efficiency of the Chinese power sector has been constantly improved in recent years. The gross coal consumption rate of power sets over 6000 kW declined from 370 gce/kWh in 2005 to 319 gce/kWh in 2014, the net coal consumption rate fell from 343 gce/kWh to 300 gce/kWh, the service power rate declined from 5.87% to 4.83%, the line loss rate fell from 7.21% in 2005 to 6.64% in 2014, the energy loss by power plants and transmission declined progressively and energy efficiency steadily improved (see Table 6-4).

6.1.2 REVIEW OF MAIN POLICIES IN PROMOTING ENERGY EFFICIENCY IN POWER GENERATION

For a long time, the Chinese government has formulated a series of policies to promote gradual improvements in the efficiency of the power sector.

Eliminate backward small and medium-sized power plants

A great quantity of old, backward, low-efficiency power plants have existed for a longer time. During 2006-2014, the Chinese government intensified its efforts to eliminate backward capacity in the power sector, issuing a mission statement for the elimination of 50 GW backward small power plants. After five years of effort, 76.83 GW in small units had been closed down, an achievement rate of 153%. The *12th FYP for Energy Conservation and Emissions Reduction* issued by the State Council called for the elimination of another 20 GW capacity in backward small power plants during 2011-2015, mainly conventional coal-fired units with capacities of under 100 MW, conventional small thermal power units with capacities of under 50 MW, oil-fired plants mainly for power generation with capacities of under 50 MW, and conventional coal-fired power units connected to the grid with capacities of under 200 MW and with their design life having expired. During 2011-2014, China eliminated a total of 22,768 GW of inefficient thermal power units, fulfilling the predetermined task of eliminating inefficient power units one year earlier than planned (see Table 6-5).

Increase energy-efficiency access threshold for new power plants

Generation efficiency varies greatly according to the size of the power plant. At present, the generation efficiency of large supercritical generation units is approximately 43%, while the efficiency of ultra-supercritical power ge-

TABLE 6-3. Total power generation and mix changes in China

GENERATION CAPACITY (100 MILLION KWH)	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Gross power generation capacity	24932	28433	32607	34445	36810	42275	47298	49838	53721	56045
Thermal power	20437	23696	27207	28030	30117	34166	39003	39255	42216	42274
Hydropower	3964	4167	4714	5655	5717	6867	6681	8556	8921	10601
Nuclear power	531	543	629	629	701	747	872	982	1115	1332
Wind power		27	57	131	276	494	741	1004	1383	1598
Solar energy								36	84	235
Others								5	3	5
Share (%)	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Thermal power	82.0	83.3	83.4	81.4	81.8	80.8	82.5	78.8	78.6	75.4
Hydropower	15.9	14.7	14.5	16.4	15.5	16.2	14.1	17.2	16.6	18.9
Nuclear power	2.1	1.9	1.9	1.8	1.9	1.8	1.8	2.0	2.1	2.4
Wind power	0.0	0.1	0.2	0.4	0.8	1.2	1.6	2.0	2.6	2.9
Solar energy	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.4
Others	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Source: China Electric Power Yearbook 2006-2015

TABLE 6-4. Efficiency of China's power sector since 2005

ITEM	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Power supply coal consumption (gce/kWh)	370	367	356	345	340	333	329	325	321	319
Power generation coal consumption of thermal power plant (gce/kWh)	343	342	332	322	320	312	308	305	302	300
Station service power consumption rate (%)	5.87	5.93	5.83	5.90	5.76	5.43	5.39	5.10	5.05	4.83
Line loss rate (%)	7.21	7.04	6.97	6.79	6.72	6.53	6.52	6.74	6.69	6.64

Note: Power plant at 6000 kW and above nationwide

Source: China Electric Power Yearbook 2006-2015.

TABLE 6-5. Elimination of outdated capacity in China's power sector during 2011-2014

	2011	2012	2013	2014	TOTAL
Elimination scale (10,000kW)	800	544	447	485.8	2276.8

neration technology can even reach figures above 45%. In addition to expanding the size of newly built plants, it is also important to improve efficiency by improving steam temperature and steam pressure. Take 600 MW units as an example: when steam temperature and pressure are improved from subcritical to ultra-supercritical, thermal efficiency can increase from 41% to 45%, and the gross coal use rate can be reduced by 20 gce/kWh.

From 2011, the National Development and Reform Commission formulated and updated the *Catalogue for Guidance of Industrial Structural Adjustment* annually, classifying the sectors in the national economy into encouraging class, restricting class and elimination class, and defining the technologies to be encouraged and developed, restricted, or compulsorily eliminated in detail.

Technologies to be encouraged include: (1) supercritical and ultra-supercritical units with a capacity of 600 MW and above; (2) centralized CHP and CCHP units with a capacity of 300 MW and above; (3) large air-cooling power generation units with a capacity of 600 MW and above in water-deficient areas; (4) combined-cycle power plants; (5) clean-coal power generation such as circulating fluidized beds, pressurized fluidized beds and integrated classification combined cycle power generation with a capacity of 300 MW and above; and (6) power generation

using fluidized bed boilers and coal gangue or inferior coal with a capacity of 200 MW and above.

Technologies to be restricted include: (1) conventional coal-fired thermal power units with a capacity of 300 MW and above; and (2) power generation units with a net coal consumption rate of 300 gce/kWh or higher, and air-cooling power generation units with a net coal consumption rate exceeding 305 gce/kWh.

Technologies to be eliminated include: (1) conventional coal-fired condensing steam thermal power units connected to the grid with a capacity below 100 MW upon maturity of service life; (2) conventional small thermal power generation units with a capacity below 50 MW; and (3) oil-fired plants mainly for power generation with a capacity under 50 MW.

The Chinese government is pressing enterprises hard to implement the *Catalogue for Guidance of Industrial Structural Adjustment* as industrial policies. The coal-fired power-generation units that have been newly constructed in recent years are basically large-size, high-parameter, high-efficiency supercritical units, and the share of small-size, low-parameter and low-efficiency units has been progressively reduced.

Generalize CHP plant and implement cogeneration transformation

Cogeneration can reduce cold-end loss and is one of the most effective means whereby thermal power units can improve energy efficiency. In China's 11th and 12th FYPs for Energy Conservation, cogeneration has been listed as a key project. In 2011, the National Development and Reform Commission revised the *Provisions on Development of Cogeneration* (combined heat and power generation). This policy calls for the following measures: (1) active support for the development of gas and steam combined-cycle cogeneration; (2) that heat-supply boilers with a unit capacity of 20 tons/hour and above and annual utilization of heat load greater than 4,000 hours, having demonstrated obvious economic benefits technologically and economically, should be transformed into cogeneration; and (3) that within the heat-supply range of the constructed cogeneration centralized heating and planned cogeneration centralized heat-supply project, no coal-fired self-provided power plant or permanent coal-fired boiler room should be constructed. Moreover, local environmental protection and technical supervision departments will not approve any more expansions of small boilers.[14]

Cogeneration (combined heat and power generation) has been rapidly developed in China in recent years. In 2014, the annual heat supply of a CHP unit with a capacity of 6000 kW and above was 3183.62 PJ. The scale of installed capacity was 283.26 MW, accounting for 30.84% of thermal power, an increase of 11.25% from the level in 2013.[15] Cogeneration units in China mainly undertake the task of supplying urban factory steam and centralized heat supply. In 2014, urban steam centralized heat supply capacity in China was 84,664 tons/hour, of which 70,372 tons/hour is from there thermal power plants, accounting for 83.12% of the total; the gross urban steam centralized heat supply was 556.14 PJ, of which 485.84 PJ was by thermal power plants, accounting for 87.36% of the total. In the same year, the urban hot water centralized heat supply capacity in China was 447,068 MW, of which 205,043 MW is from thermal power plants, accounting for 45.86% of the total. The gross urban hot water centralized heat supply was 2765.46 PJ, of which 1151.90 PJ was from thermal power plants, accounting for 41.65%.[16]

Implement energy-saving technical transformations

The Chinese government began to provide subsidies for energy-saving technical transformation projects to enterprises from 2006. The subsidy given to enterprises is determined according to the energy savings made by the project. In 2006, the incentive standard was 200 RMB/tce in the eastern regions and 250 RMB/tce in the central and western regions. The threshold for obtaining such a subsidy from central government is 10,000 tce. The government requires that the energy savings declared by the enterprise must have been directly produced by the enterprise through technical transformations and that this can be checked and ratified. In 2011, the central government increased the incentive standard to 240 RMB/tce for the eastern regions and 300 RMB/tce for the central and western regions. The incentive threshold for individual projects was lowered to 5000 tce. From 2006 to 2013, a number of power plants implemented energy-saving technical transformations and benefited from this policy, which was abolished by the Ministry of Finance in 2013.

By means of the comprehensive interaction of the above policies, the energy efficiency of the power sector has been markedly improved. In 2015, the average gross coal consumption rate of coal-fired power generation in China was about 315 gce/kWh, close to the international advanced standard.

14 *http://www.nea.gov.cn/2011-11/22/c_131262611.htm*

15 *Data Source: Summary of Power Industry Statistics (2014).*

16 *Data Source: China Urban-Rural Construction Statistical Yearbook 2014.*

6.2 PROSPECTS OF ENERGY CONSUMPTION IN THE POWER GENERATION SECTOR (TWO SCENARIOS, BY 2050)

The research group adopts scenario analysis when studying the energy efficiency HIOs in the power sector, establishing two scenarios according to the different prospects of technological and policy development in the future, namely the reference scenario and the intensified energy-saving scenario. By way of comparing the difference between the two scenarios, guidance will be provided for determining HIOs.

6.2.1 METHODOLOGY

The methodology used for the power sector is mainly divided into two parts: scenario design and model design. Scenario design is directed at qualifying the two different development prospects; model design is used to describe the modeling tools deployed by the research group and the creation of model framework.

Scenario design

After thorough discussion, the research group decided that the reference and the intensified energy-saving scenarios for the power sector should be determined as follows:

(1) Reference Scenario

The Reference Scenario covers the prospect of future development obtained mainly by continuing the existing policies before 2010 and appropriately taking into account the continuation of the trends of technical advancement in the power sector. Specifically:

- The technologically mature and most feasible cases of best practice in 2010 will be generalized and applied to some extent. The Energy efficiency will be improved, but the speed of improvement may be very slow;
- Progress with of greenhouse gas emission-reduction mechanisms such as carbon taxes and carbon emissions trading will be very slow;
- Coal-fired power is characterized by better economy, stronger competitiveness and greater development inertia. It will be difficult to replace fossil energy comprehensively with renewables in the medium and long terms.

(2) Intensified Energy-saving Scenario

The Intensified Energy-saving Scenario is mainly a scenario in which the energy efficiency of China's power sector will be further improved and the proportion of renewable energy sources will be markedly increased by intensifying efforts to generalize advanced technologies and alter power structures. More specifically:

- Power generation enterprises and electric grid enterprises should attach importance to the management of energy efficiency. Currently mature and feasible high energy-efficient technologies and best practices will be generalized and applied maximally in the near and medium terms.
- In the medium and long terms, measures will be taken to control carbon dioxide emissions in the power sector. The power generation costs of fossil fuels will gradually be increased through carbon taxes, carbon emissions trading, etc.
- In medium and long terms, the more rapid decline in the cost of renewable energy sources will accelerate the replacement of coal-fired power, and coal-fired power plants will gradually be phased out after the expiration of their service lives.
- The reform of the power system will be smoothly carried out. The marketization of grid power generation will be successful in medium and long terms. New technologies such as demand-side response, large grid long-distance power transmission, etc. will be applied on large scale.

Selection of modeling tools and design of model framework

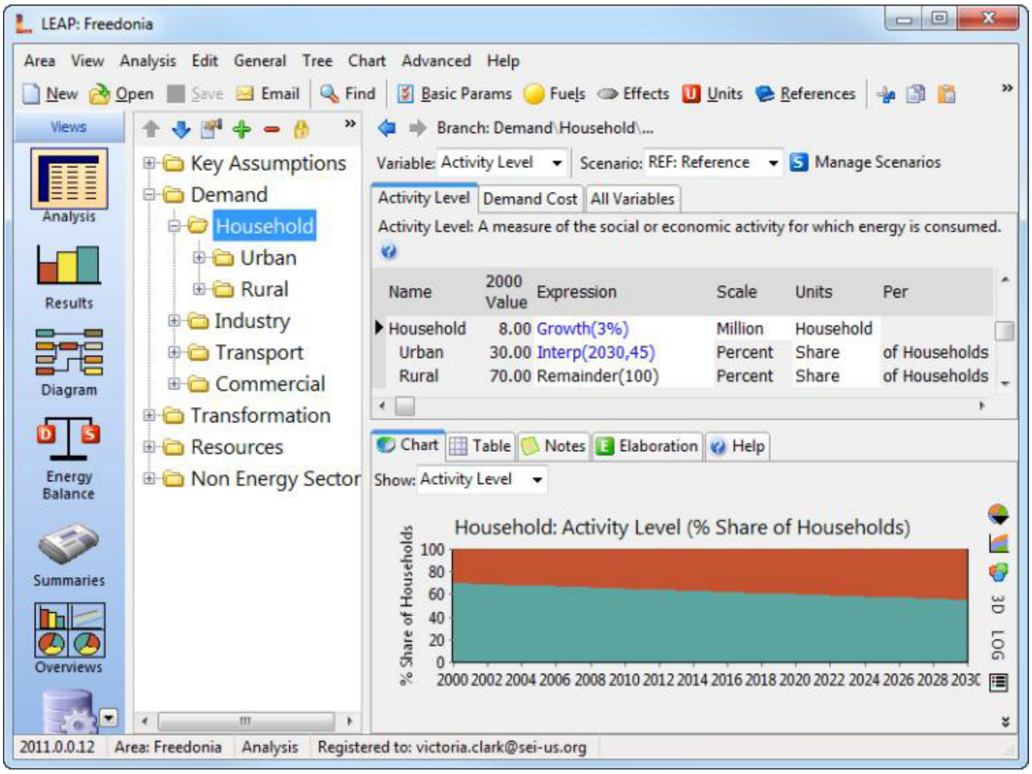
(1) Introduction of LEAP model

In the research described in this chapter, the research group adopts a LEAP model as the main quantitative analysis tool. LEAP is the abbreviation for 'long-range energy alternatives planning' system. The LEAP model is an energy-environment model developed by the Stockholm Environment Institute (SEI) Boston/Dallas Branch. This model is itself a 'bottom-up' simulation model that can be used for calculating energy consumption demand, loss of energy processing and conversion, and the pollutant and greenhouse gas emissions caused by this. Since 1995es, more than 190 countries and thousands of organizations have gradually adopted the LEAP model to conduct national/regional energy strategic research and greenhouse gas emission evaluations.

Through decades of development, the software functions of the LEAP model have constantly been perfected, and the interface has become increasingly friendly (see Figure 6-4), establishing a good reputation with users from all around the world.

Compared with other energy-planning models, one outstanding advantage of the LEAP model is its comparatively transparent data and the fact that the model's requirements regarding input data are relatively flexible. Users may select the form and quantity of input data according

FIGURE 6-4. **Schematic diagram of the LEAP Model**



to the characteristics of the research topic and data availability, unlike other models with rigid forms of data input and higher requirements regarding the perfection level of the data, which cannot be computed if some data is lacking, such as price or cost data. The LEAP model, as a flexible model with low initial data requirements, can meet the different needs of different users and without heavy data input and high expertise requirements on the users.

(2) LEAP model framework for the power sector

In the energy model established by the research group, the industry, building and transportation sectors will all predict terminal energy consumption demand in the future, of which electricity and heat demand, etc. is transmitted to the power sector for analysis and measurement. The primary energy consumption of the power sector, the non-power processing and conversion sector, and the terminal energy consumption sector are totaled up to provide a figure for the gross national primary energy consumption (as shown in Table 6-5).

The power sector studied in this chapter not only includes electricity generation, but also heat supply and the transmission and distribution of both it and electricity. The research group believes that, although the energy consumption of a part of the power and heating power production department in the energy balance sheet is included in the terminal department, this has been adjusted in the present analysis. This part of energy consumption will be treated as included in the power sector.

The power module of the LEAP model designed by the research group is divided into transmission loss, electricity-only supply, CHP and heat supply, of which the electricity-only generation part is divided into coal-fired generation, gas-fired generation, oil-fired generation, nuclear power, wind power, hydropower, solar energy power generation, biomass power generation and geothermal power generation. In addition, the coal-fired electricity-only power units are also divided into six categories: units of 1,000 MW and above, of 600-1,000 MW, of 300-600 MW, of 200-300 MW, of 100-200 MW, and of 60-100 MW according to size (as shown in Figure 6-6).

6.2.2 KEY ASSUMPTIONS

The main assumptions of the model input include transmission loss, the power generation efficiency of various generation units, the priority of various modes of generation, power generation costs, capacity in base year, and other parameters.

Energy efficiency of power plants

(1) Energy efficiency of power plants

The research group abides by the objective law that the larger the capacity of the unit, the higher its efficiency will be when the energy efficiency of the current and

FIGURE 6-5. **Positioning of the the power sector model in the entire energy model**

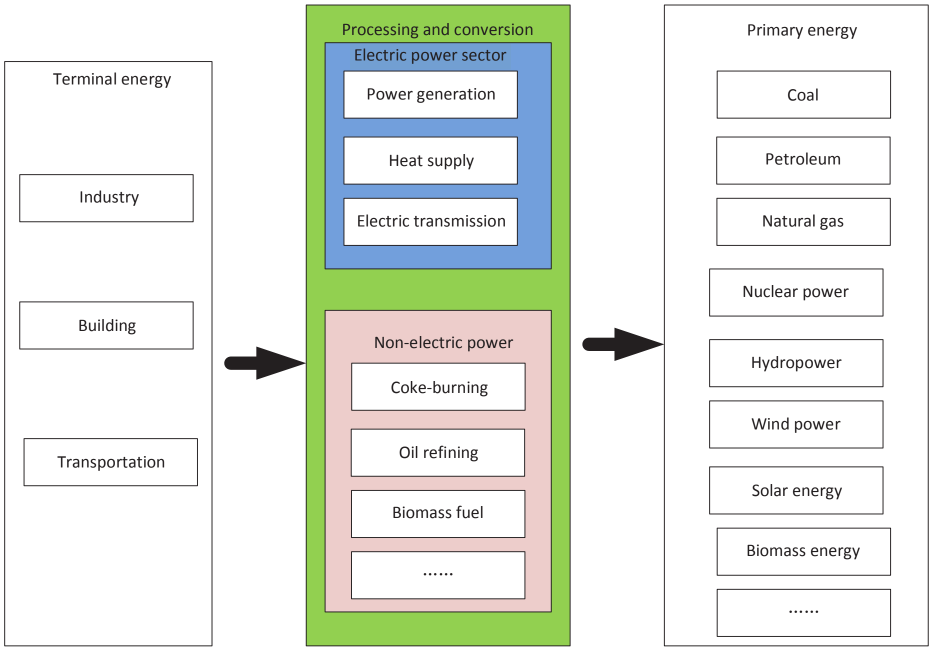
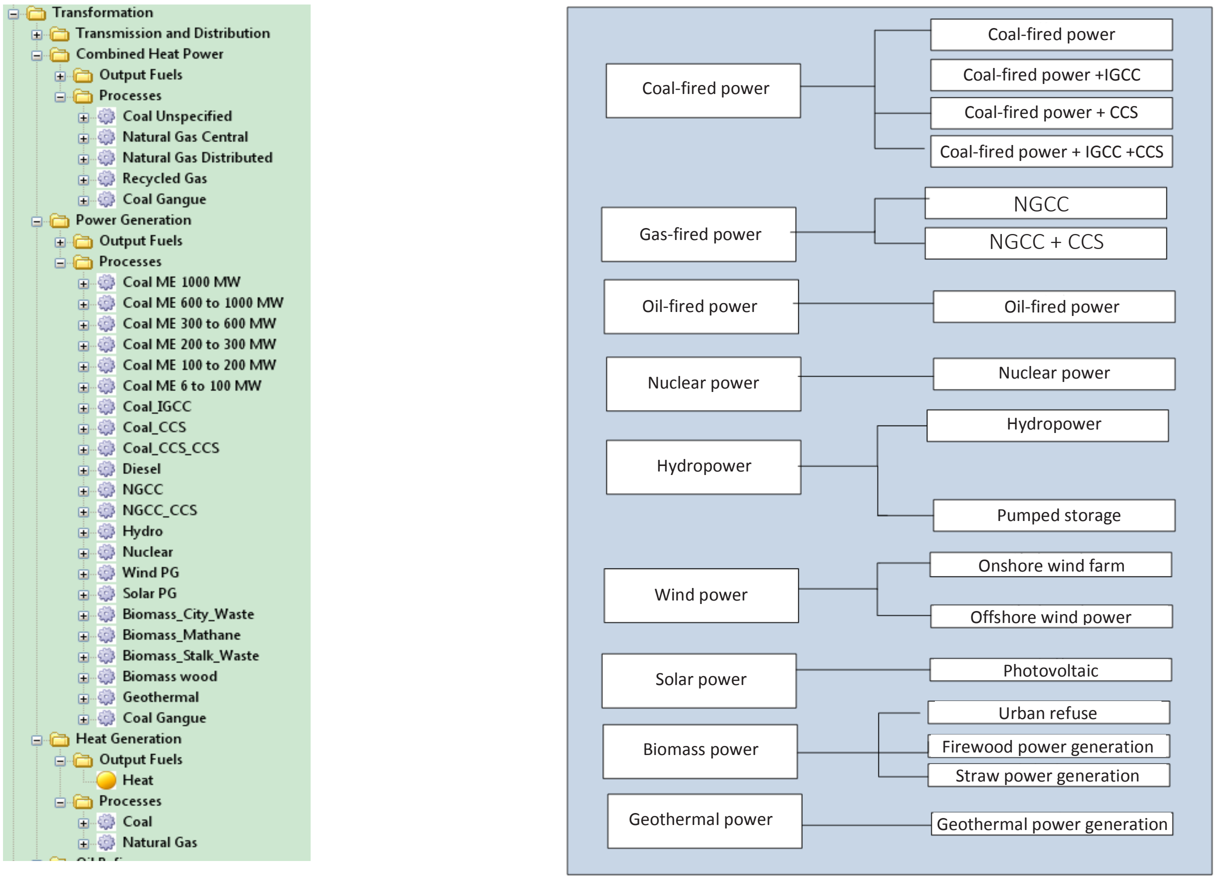


FIGURE 6-6. **Structure of the LEAP Model for power sector**



future power plants is taken into account. Table 6-6 shows the status of the power supply energy efficiency of the thermal power generation unit at different capacity classes in some large power generation enterprises in China in 2012. It can be observed that the difference between the 600 MW class and the 1000 MW class in coal consumption is 22 gce/kWh, that between the 300 MW class and the 600 MW class is approximately 12 gce/kWh, that between the 350 MW class and the 300 MW class is 8 gce/kWh, and that between the 200 MW class and the 600 MW class is approximately 30 gce/kWh.

The research group assumes that energy efficiency will still be progressively improved after the various classes of thermal power generation units constantly implement the transformation of energy conservation . The research group assumes that energy efficiency is very slow to improve in the reference scenario, accelerating in the intensified energy-saving scenario. At present, countries around the world are working hard to surmount the ultra-supercritical coal-fired power generation technology at a steam temperature of 700°C. Once this technology has been surmounted, the main steam parameter will have been improved to 35MPa/700°C/720°C. Power generation efficiency will be further improved by approximately 50%, and the net coal consumption rate will be reduced to below 260gce/kWh. If high-efficiency coal-fired power generation technology is forcefully promoted, it will be possible to realize this ultra-high energy-efficiency objective.

In model research, the research group assumes that the coal consumption of 1,000,000kW-class coal-fired generation units in 2010 was 274 gce/kWh, equivalent to 44.8% of power generation efficiency. In the reference scenario, assuming that efficiency has already reached a quite high level and it is difficult to continue improving it, the net coal consumption rate of this type will be reduced to 270 gce /kWh (equivalent to improving power generation efficiency by 45.5%) by 2050. In the intensified energy-saving scenario, through a series of systematic transformations, by 2050 coal-fired power generation efficiency will be further improved by 47.3%, a net coal consumption rate of 260 gce/kWh, demonstrating that the intensity level is quite large (see Figure 6-7).

Gas turbines and natural gas and steam combined cycles (NGCC) are the main modes of natural gas power generation in the developed countries at present. The production principle is to make use of natural gas through its direct combustion in gas turbines and to enable gas turbines to drive generators to generate electricity. At this moment, it is a single-cycle form of power generation. If the high-temperature tail gas produced by the gas turbine is put through a waste-heat boiler after generating high temperatures and high pressure steam, it will cause the steam turbine to drive the generator to generate electricity. At this moment, it is a combined-cycle form of power generation. Research indicates that the power supply efficiency of advanced and mature gas turbines operating independently will be approximately 40%. The net efficiency of combined-cycle power generation may be more than 58%, the highest level in today's practical power generation technology. The initial inlet temperature of the latest gas turbine may reach more than 1600°C. The power generation efficiency of combined-cycle technology has exceeded 61%. In model research, the research group assumes that China will use the gas-steam combined cycle as the main type in the future. In the reference scenario, the power generation efficiency of natural gas will be improved from 56.8% in 2010 to 58% in 2050. In the intensified energy-saving scenario, efficiency will be further improved to 61.5% (see Figure 6-8).

TABLE 6-6. Efficiency levels of the thermal power generation units at different capacity classes in some large power enterprises in China in 2012

CAPACITY LEVEL	NUMBER OF SETS	GROSS INSTALLED CAPACITY (10 MW)	STANDARD COAL CONSUMPTION OF POWER SUPPLY (GCE/KWH)
All units	1295	42411	318
Grade of 900-1000MW	31	3132	290
Grade of 600MW	265	16400	312
Grade of 350MW	68	2387	318
Grade of 300MW	447	13920	326
Grade of 200MW	155	3183	341
Grade of 120-165MW	116	1655	347
Grade of 100MW	21	213	350
Below the grade of 100MW	148	361	367
Gas turbine	44	1161	229

FIGURE 6-7. Power generation efficiency of coal-fired units under the Reference Scenario and the IEC Scenario

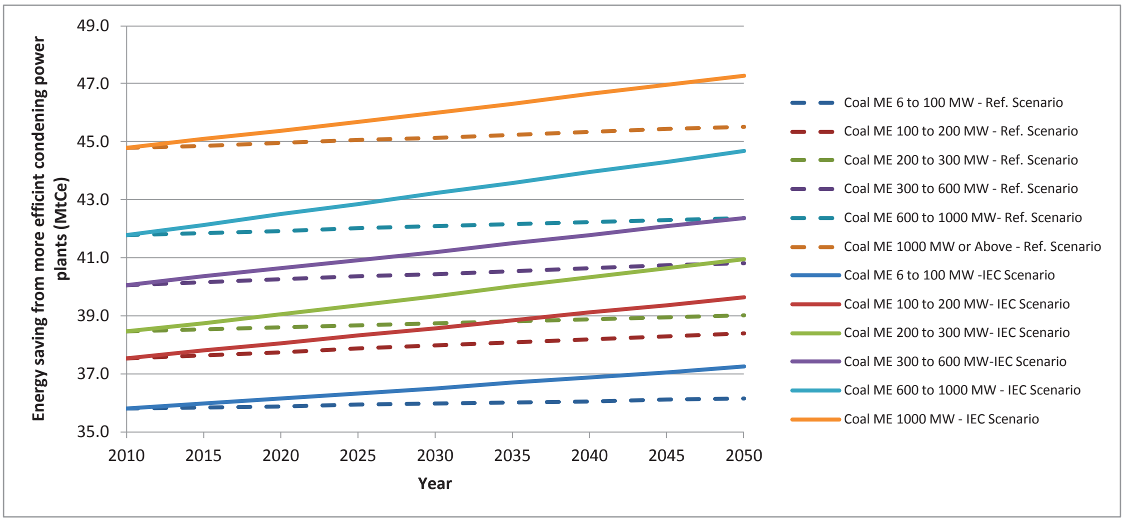
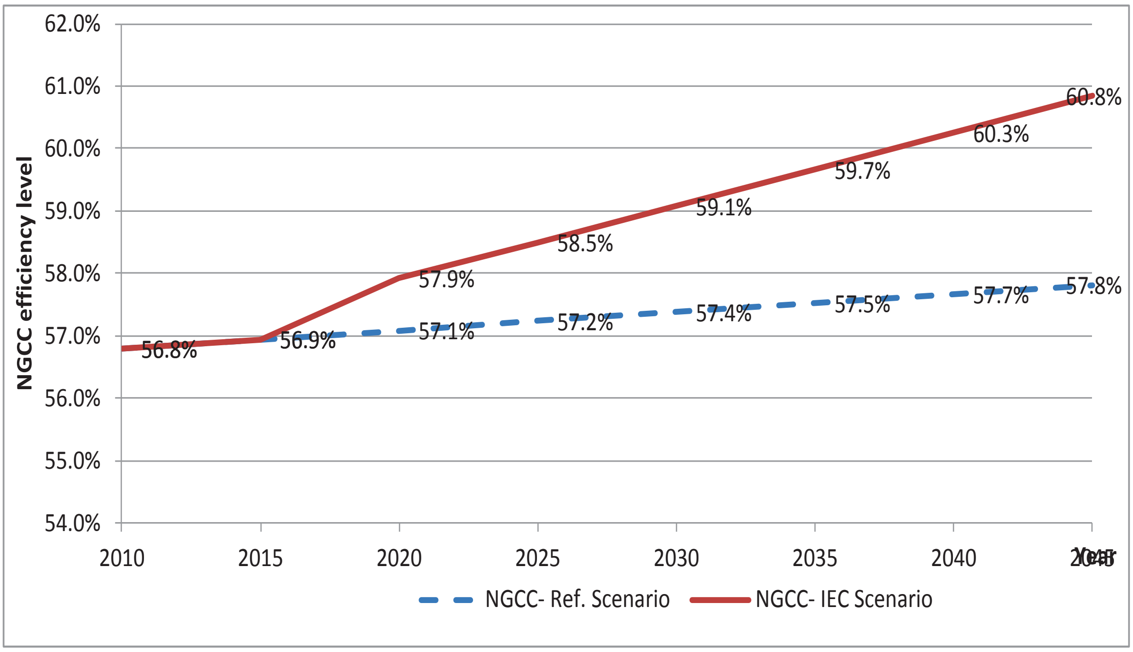


FIGURE 6-8. Efficiency levels of the gas-fired power generation units under the Reference Scenario and the IEC Scenario

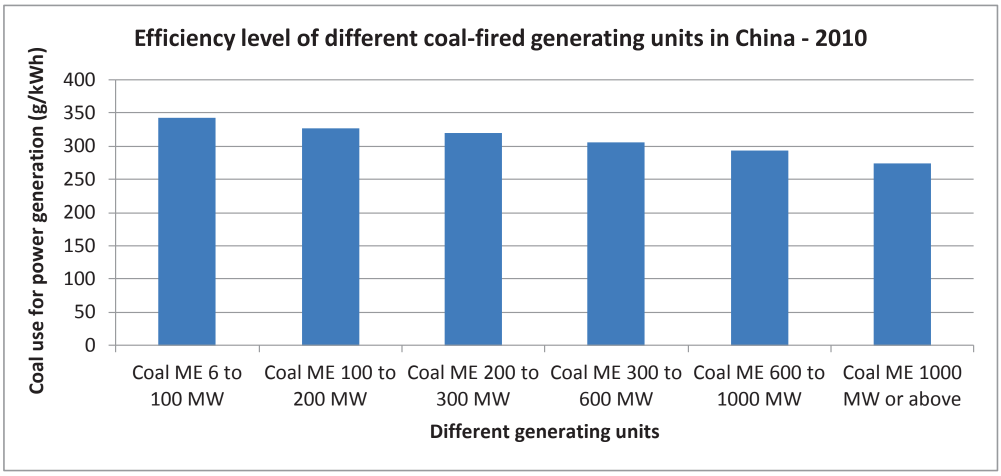


(2) Energy efficiency of power transmission system

Theoretically, there are many factors affecting energy loss from the electric grid, such as the materials of which the grid cables are made, the coverage of the grid, the regulatory capacity of grid transmission and distribution, the power load density, the characteristics of the power distribution, the power transmission distance, the grid management level, etc. After years of efforts, grid loss has declined consistently in China. The proportion of line loss in transmission capacity declined from 7.2% in 2005 to 6.6% in 2014.

From the perspective of the various factors affecting grid line loss in China in the future, this not only includes increasing energy consumption, but also declining energy consumption. Resources for coal-fired power, hydropower, wind power and photovoltaic power generation are abundant in the western regions in China, while the electricity load is mainly concentrated in the eastern regions. Because of the regional difference between resources for power generation and load, China will certainly improve its long-distance power transmission capability in the future. This will increase the line-loss level

FIGURE 6-9. Efficiency levels of coal-fired power plants at different classes in 2010



of the electricity grid in China, which in the future will not be comparable to developed countries with higher load densities such as Japan, South Korea, etc. Meanwhile, along with advances in grid-dispatching technology and the optimization of the materials used for grid lines, especially the wide application of digitalized grid regulation technology and the popularization of new materials such as high-temperature superconductors, etc., the energy efficiency of the electricity grid will be improved and line loss constantly reduced. By synthesizing the two factors above, the research group believes that the transmission loss to the electricity grid in medium and long terms will be slowly reduced. In the reference scenario, the line loss will be reduced from 6.3% in 2010 to 5.5% in 2050, and in the intensified energy-saving scenario, line loss in 2050 will continuously decline to 4.5%, being reduced by 1 percentage point more compared with the reference scenario.

Economy of various power plants

During research, the research group collected and analyzed economic data for various power plants, including coal-fired power generation, gas power generation, hydropower, nuclear power, wind power, photovoltaic power generation, etc.

(1) Coal-fired units

The cost of coal-fired plants can be divided into three elements: initial investment, operating and maintenance costs, and fuel costs, of which the initial investment is related to construction capacity and installed capacity and is generally represented by investment in unit installed capacity (also called capacity cost). The operating and maintenance costs are related to human resources costs and other factors, while the fuel cost is related to the price of the fuel used. At present, China has mastered the design, manufacture, construction, debugging and operational technology of supercritical 600 MW-class thermal power generation units, as well as, basically, those of 1,000 MW-class supercritical units. Large turbine condenser air-cooling technology, especially direct air-cooling technology, will be developed rapidly. As traditional and mature power generation technologies, investment in and the construction of large coal-fired power plants in different places will be conducted according to national standard, though the difference in investment levels is not great. In this research, the initial investment in coal-fired power generation unit will be calculated at 4,000 RMB/kW (see Figure 6-9).

(2) Gas-fired units

Natural gas as a clean and high-quality energy will play important role in optimizing China's energy consumption structure, improving the atmospheric environment and controlling greenhouse gas emissions. Due to the role of market, natural gas-based gas turbine technologies have achieved rapid development over the past twenty years. Since the start of this century, China has achieved better effects in markets for technology, in the localized manufacture of gas-turbine equipment and in the development of domestic gas-turbine technology. Binding bids have accounted for eighteen power stations and 41 gas turbine generator sets. Especially in supporting the 'West-East natural gas transmission' project, a group of natural gas-combined cycle units have been constructed in load centers. The specific investment costs of gas turbines and their combined cycle units are lower than those of coal-fired steam-turbine power stations. In this research, it is assumed that the capacity cost of combined-cycle power plant in the base year is 3,000 RMB/kW.

(3) Hydropower

Hydropower investment is closely related to the geographical and geological conditions, immigration conditions, etc. of the factory site. Investment in unit installed capacity varies greatly. Along with increases in investments in migration compensation in the future, a certain level of increase may appear in the unit's initial investment. In this research the hydropower capacity cost in the base year will be calculated at 10,000 RMB/kW.

(4) Nuclear power

Nuclear power is a clean, safe, economical energy source and one of the zero-carbon alternative energy sources for scale generalization in the near and medium terms. In the past twenty years, the international focus has been on the construction of the third generation of pressurized water reactor power plants. China has basically laid the foundations and set the conditions for scale development in the independent design, manufacturing, construction, operation and site resources reserves of pressurized water reactor power plants, as well as the safety and economy of the supply and operation of nuclear fuels. From the perspective of the construction costs of both established and in-construction nuclear power stations, the cost level of the initial investment in nuclear power in China has been reduced from 2,068 US$/kW in Daya Bay to 1,385 US$/kW in the Qinshan Phase-II project. This research assumes that the capacity cost of nuclear power construction in the base year is 10,000 RMB/kW.

(5) Wind power

In recent years, the development of wind power technology has mainly been concentrated in the expansion in the scale of the monomer unit. Reducing costs is one of the important tasks for the development of wind power technology. Along with the increasing maturity of wind power manufacturing and development technologies and the scale development of wind power, wind power costs have been constantly reduced in the past twenty years. In the development of onshore wind power, the cost of wind power units accounts for approximately 65% - 84%; the operating and maintenance costs of wind power (including service, spare parts, insurance, management, other expenses, etc.) account for approximately 25%.

The average investment in the installed capacity of onshore wind power units in China is approximately 9,000 RMB/kW. It is estimated that the average investment in the unit installed capacity of onshore wind power in China in 2030 and 2050 will be greatly reduced.

(6) Solar power generation

Since 2011, China has been the largest manufacturer of solar energy cells and components in the world, and output exceeded 50% of global production in 2012. Under the dual driving factors of continuous technical progress and fierce industrial competition, in the past ten years the price of solar battery packs has been rapidly reduced from 46 RMB/W to 4.6 RMB/W, and the cost per kWh of power to approximately 1 RMB/kWh. The cost of photovoltaic power generation, on the other hand, approaches that of conventional power generation.

It is estimated that the price of solar battery packs will be further reduced in the future, from the present 8,500 RMB/kW to 7,000 RMB/kW by 2030. The conversion efficiency of monocrystalline silicon and polysilicon components will be improved from the present 17% and 16% respectively to 25% and 24% in 2030.

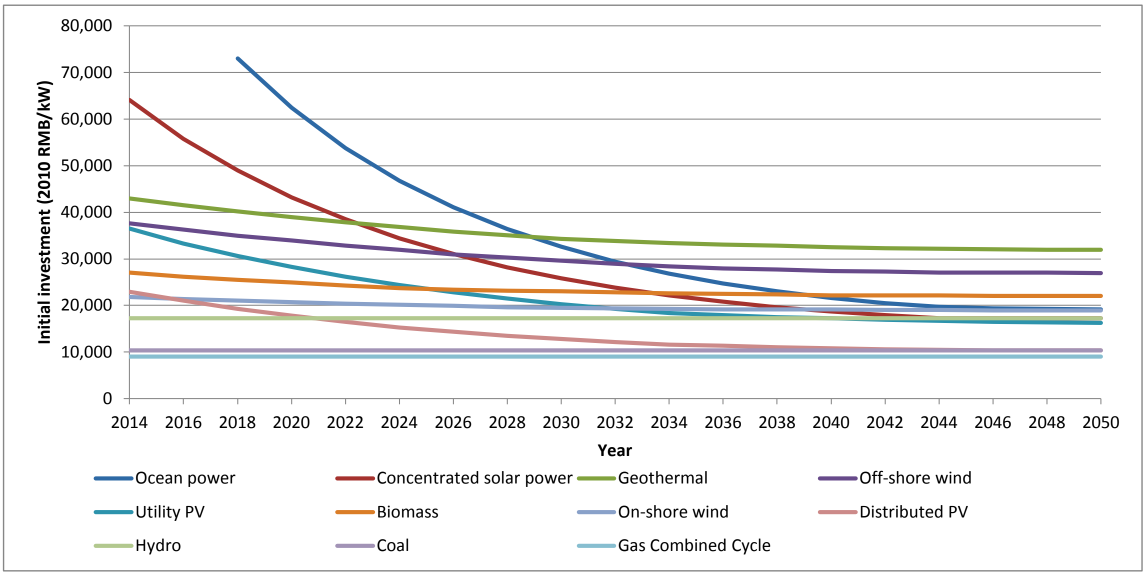
(7) Biomass power generation

The biomass power generation industry has developed rapidly in China in recent years and has become the most mature and largest field in modern biomass energy utilization technology. The cost composition of biomass power generation is similar to the cost of coal-fired power generation in being divided into three parts: initial investment, equipment operation and maintenance costs, and fuel costs.

At present, the initial investment cost of biomass power generation is 8,600 - 11,000 RMB/kW. The cost of most projects falls within a range of between 9,000 -10,000 RMB/kW. Since the investment cost has no direct relation to regional distribution, in this research, the initial investment of biomass power generation projects in the base year is calculated at 9,500 RMB/kW.

From the perspective of time scale, due to the progress made in power generation technology, initial investment in various modes of power generation will vary over time. Therefore, the price relationship between the unit initial investments of various forms of power generation will also vary over time, further affecting the decision-making of power investment enterprises. The research group assumes the future changes in initial investments in unit installed capacity in various modes of power generation that are shown in Figure 6-10. It is estimated that, due to scale effects and technical progress in renewable energy sources, capacity costs will be greatly reduced in the next twenty years. At the same time, since the room for technical progress in fossil energy power generation is small and the scale benefits almost saturated, declines in future capacity costs will be limited. New changes such as these will be favorable to the large-scale development of renewable energy sources such as wind power, solar power, etc.

FIGURE 6-10. Initial investment costs of different power generation technologies



Fuel costs of various power plants

The research group also assumes that prices for the fuel used for future power generation will be as shown in Figure 6-11. In this context it is estimated that, as the requirement for the world to respond to climate increases in intensity, the future price of oil and natural gas in China will be gradually increased. As the main source of energy of China, the price of coal will see stable growth. At the same time, resources such as straw, methane and firewood used for power generation will be considerably increased with the rise in human resources.

6.2.3 ANALYSIS OF CALCULATION RESULTS

Given the above assumption, the research group estimated the development of the future power sector by making use of the LEAP model. The results are as follows:

FIGURE 6-11. Fuel cost changes of different power generation technologies

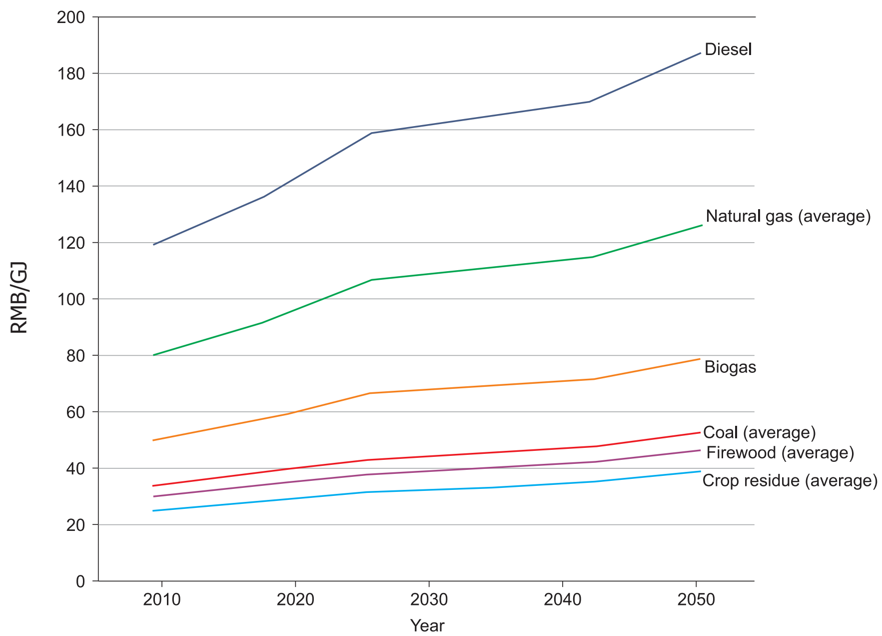
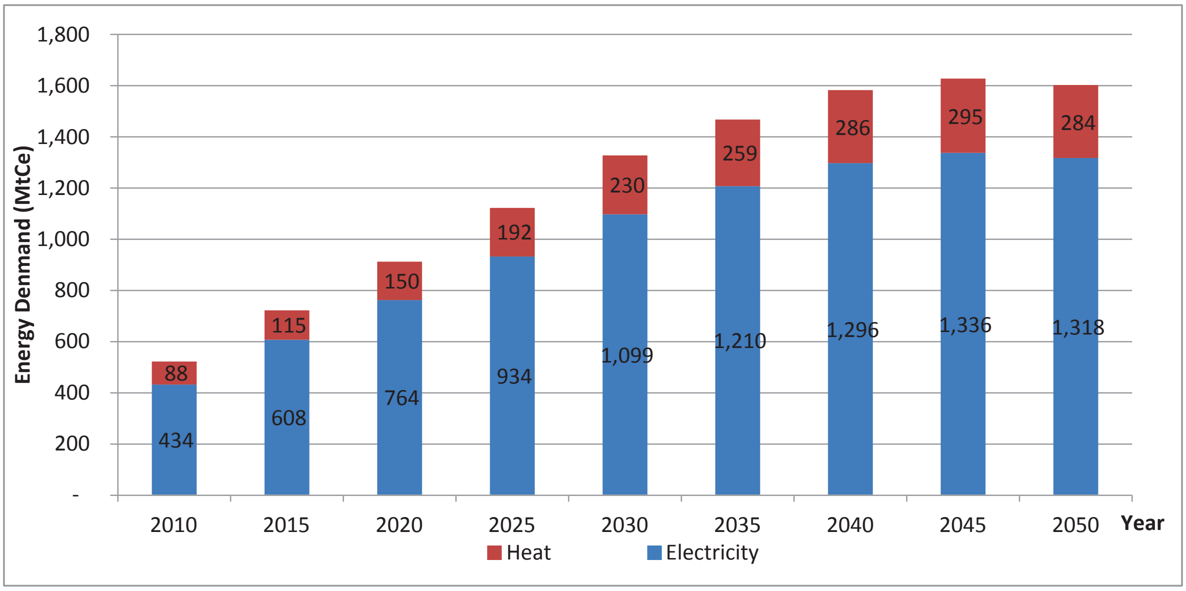


FIGURE 6-12. Future terminal power demand and heat demand in China



Power and heating power demand

Figures for power and heating power demand used by the research group are worked out with reference to the situation in the terminal energy consumption sector, including industry, building, transportation, etc. in the reference scenario. In the reference scenario, future power demand and heating power demand in China will both see great growth. By 2050, power demand will be 3.0 times what it was in 2010, and heating power demand 3.2 times (as shown in Figure 6-12). In the intensified energy-saving scenario, future terminal power demand and heating power demand will be greatly reduced compared with that in the reference scenario.

It should be noted that, in order to better reflect the impact of improvements in the energy efficiency of the power sector on energy demand, the research group uniformly adopted terminal power demand and terminal heating power demand in the reference scenario as the basis for analyzing this impact, instead of the terminal power demand and heating power demand in the intensified energy-saving scenario. The calculation may therefore overestimate the energy saving potential of the power sector to some extent. Therefore, when the entire energy system is analyzed and the national amount of energy savings calculated, energy savings in the power sector as measured in this chapter should not be added directly to the figure for energy savings in industry or the building and transportation sectors.

Difference between modes of power generation in the two scenarios

Estimating changes in the scale and structure of installed power generation capacity in the future forms an important basis for formulating development plans for the power sector in the future. The total scale of national installed power generation capacity and the variation trend in the power structure over time as obtained from the research group's model analysis are shown in Figure 6-13.

In the reference scenario, in order to meet the constant growth in power demand, the scale of the main power generation modes, including coal-fired power, gas power, hydropower, nuclear power, wind power, photovoltaic power generation, etc., will be markedly increased. Of this, coal-fired power will be increased from 660 GW in 2010 to 2100 GW in 2040, wind power from 30 GW to 910 GW, and photovoltaic power generation from almost zero to 1200 GW. In respect of coal-fired power generation units, the development of cogeneration units will not be so rapid. Comparatively speaking, in the intensified energy-saving scenario, the installed capacities of wind power, photovoltaic power and nuclear power will be higher. By 2050, the installed capacity of wind power will be increased from 910 GW to 1600 GW, of photovoltaic power generation from 1200 GW to 2500 GW, and of nuclear power from 350 GW to 400 GW (see Figure 6-14).

Energy Saving in the Power Sector in Two Scenarios

In the two scenarios, great differences appear in the consumption of fossil fuel. In the reference scenario, fossil-fuel consumption in the power sector will be increased from 1.02 Gtce in 2010 to 1.78 Gtce in 2035; the-

FIGURE 6-13. Installed power-generation capacity under the Reference Scenario in China

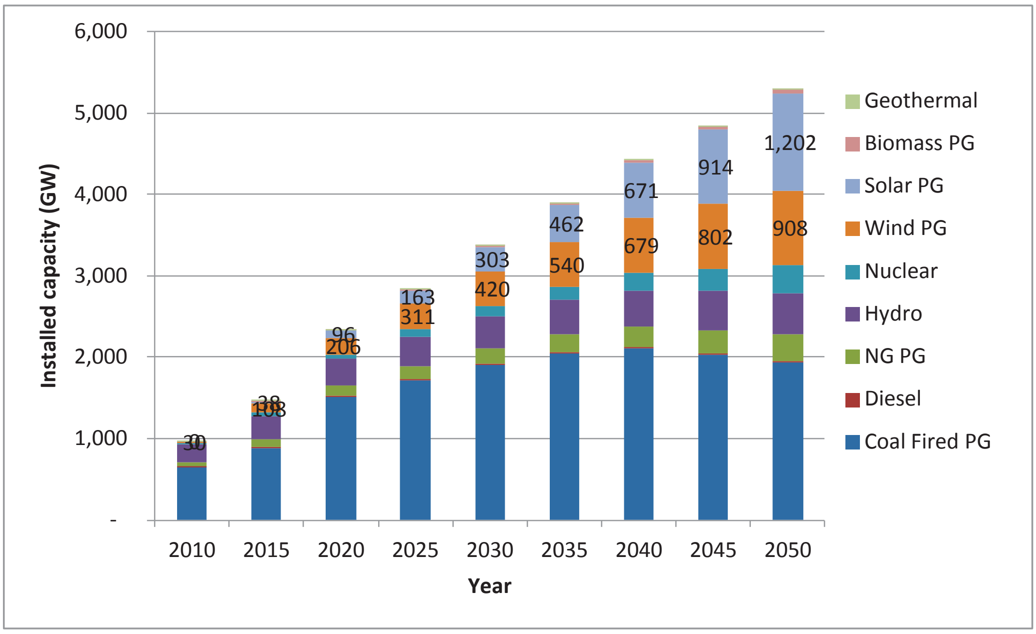
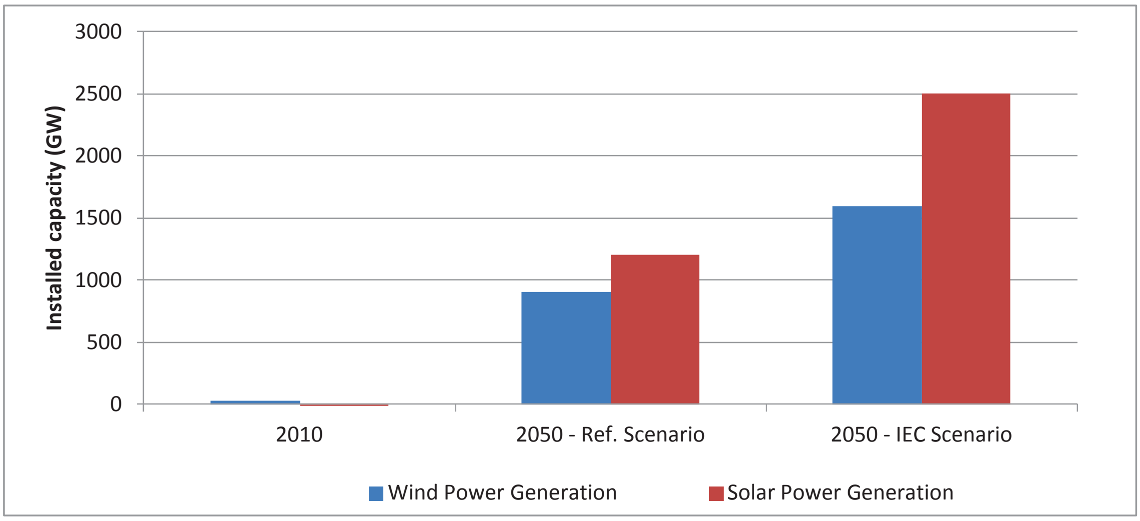


FIGURE 6-14. Installed capacity of wind power and solar PV in China under the Reference Scenario and the IEC Scenario



reafter, it will be reduced to 1.05 Gtce, the peak value appearing around 2035. In the intensified energy-saving scenario, the peak value of fossil-fuel consumption in the power sector will appear around 2030, approximately five years ahead compared with the reference scenario. The peak value will be 1.61 Gtce, reduced by 180 Mtce compared with that in the reference scenario. By 2050, fossil energy consumption in the intensified energy-saving scenario will be lower than that in the reference scenario by 341 Mtce. This reflects the comprehensive effects in improving the efficiency of energy technology in China and the structural adjustment of the power generation and heating power sectors in the future.

It is worth mentioning that, in the intensified energy-saving scenario, fossil energy is mainly consumed by way of combined heat and power generation and heat supply. The fossil-fuel energy consumed by combined heat and power generation as a share of total fossil energy consumption is up to 70.0%; fossil fuel use in the reference scenario by 2050 will be only 30.7% used for combined heat and power generation and 51.7% used for electricity-only generation (see Figure 6-16). Fossil-fuel energy-based coge-

FIGURE 6-15. Fossil fuel consumption in China under the Reference Scenario and the IEC Scenario

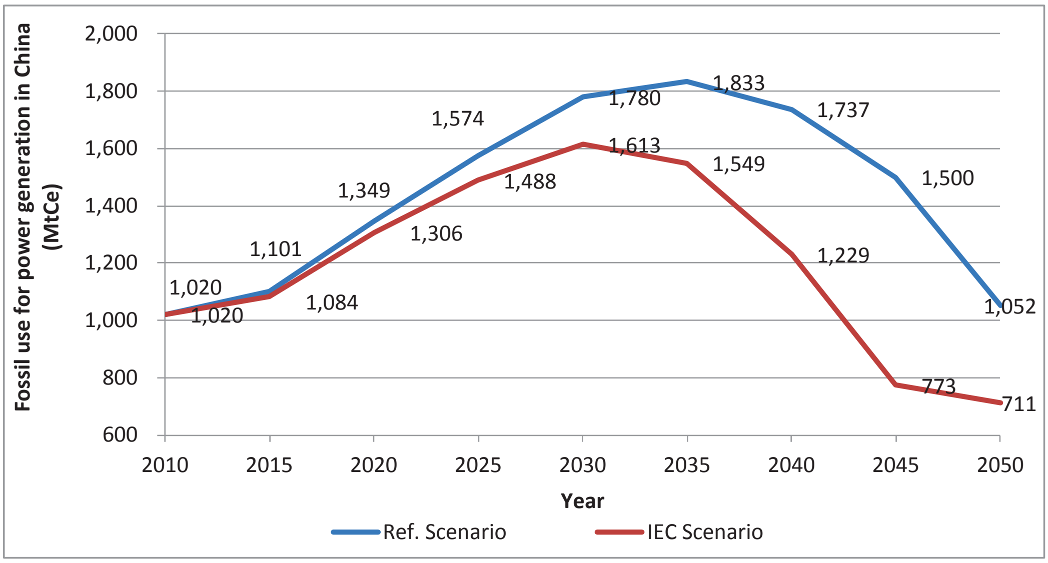
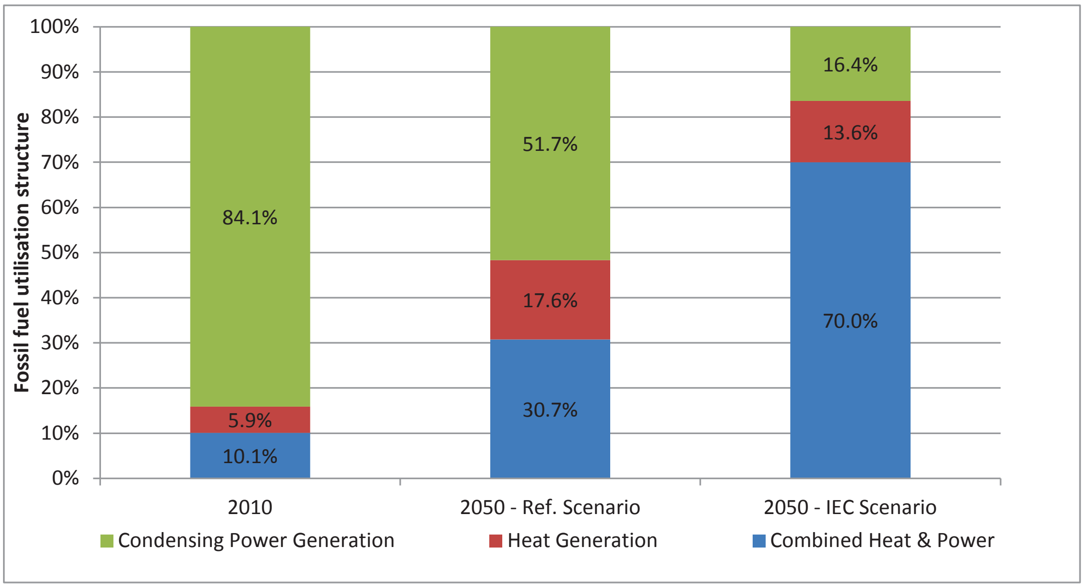


FIGURE 6-16. Different mixes of fossil fuel consumption under the Reference Scenario and the IEC Scenario



neration will be difficult to replace by renewable energy source power generation. This explains why gross fossil-fuel demand will still be maintained and will not decline to some extent after 2045 (see Figure 6-15).

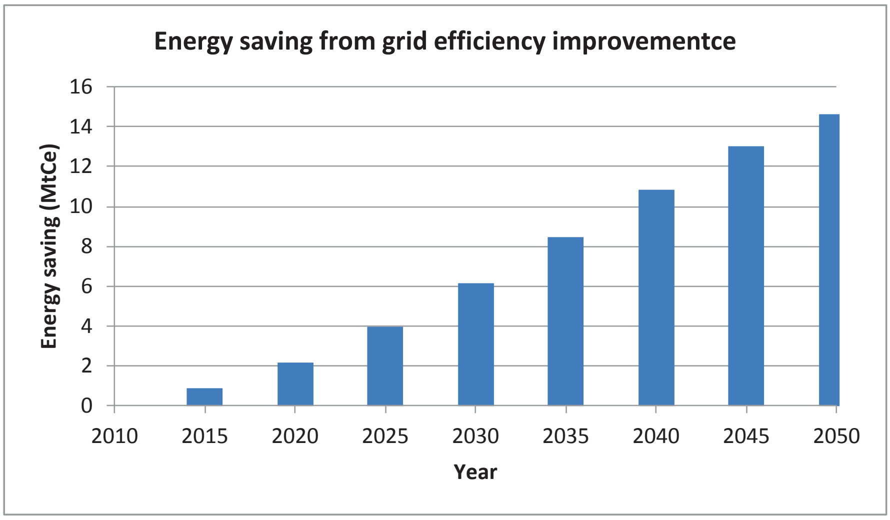
Energy savings resulting from the improved transmission efficiency of the electric grid

Model analysis indicated that, in reference scenario and intensified energy-saving scenario, the energy saving amount of grid transmission and distribution line loss resulted from the improvement in grid efficiency will be gradually expanded. Compared with reference scenario, by 2050, the improvement in grid energy efficiency in intensified energy-saving scenario will bring in the energy saving amount of 15 Mtce (as shown in Figure 6-17).

Energy savings resulting from the improved efficiency of condensing power generation units

Model analysis indicates that, in both the reference scenario and the intensified energy-saving scenario, as the efficiency of pure condensing power generation units is improved, the fossil-fuel consumption of the pure power

FIGURE 6-17. **Energy saving from improved grid efficiency**



sector will be reduced. The energy savings represented by investments in fossil-fuel consumption (the investment in renewable energy sources is not included) will be gradually improved. Compared with the reference scenario, by 2050, continuous improvements in the efficiency of thermal power generation units in the intensified energy-saving scenario will produce energy savings of 56 Mtce (as shown in Figure 6-18).

Energy savings resulting from the expanded scale of CHP

Cogeneration, as a high-efficient and energy-conserving mode of power generation and heating, will effectively improve the utilization rate of fossil fuels after large-scale generalization. After expanding the power generation and heating capacity of cogeneration units, the installed scale and generation capacity of pure condensing power generation units will be reduced. The demand for boiler heat supply will also be reduced. Therefore, when the energy saving amount resulting from the expansion of

FIGURE 6-18. **Energy saving from improved power generation efficiency of pure condensing units**

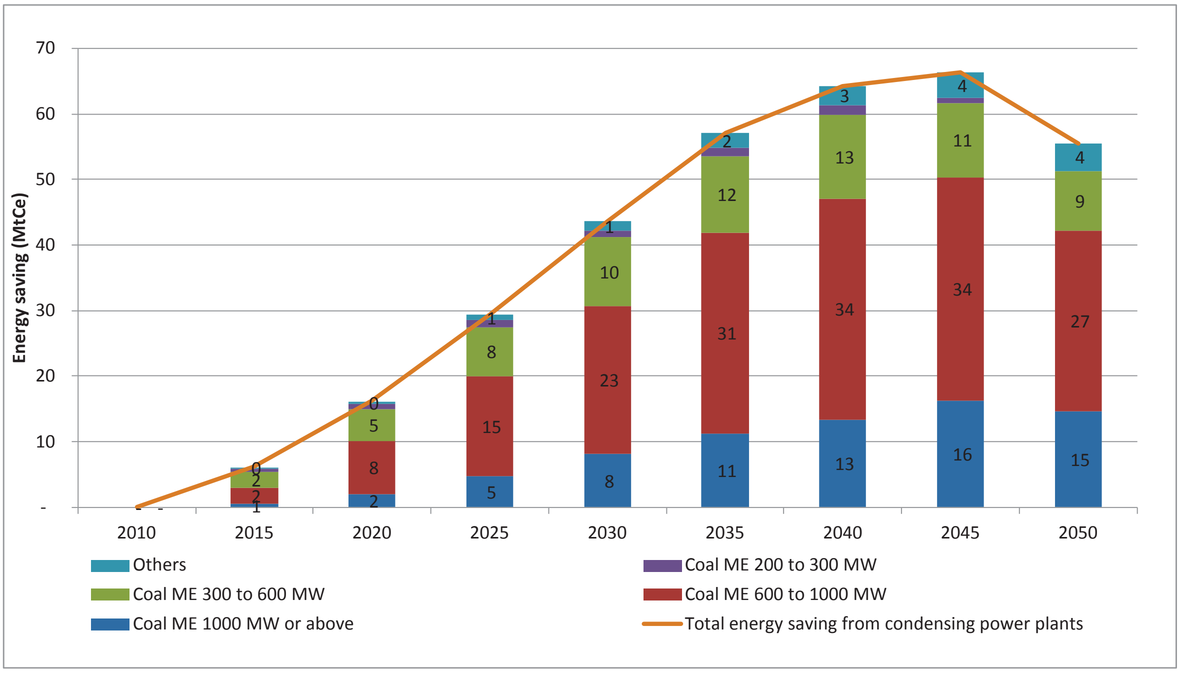
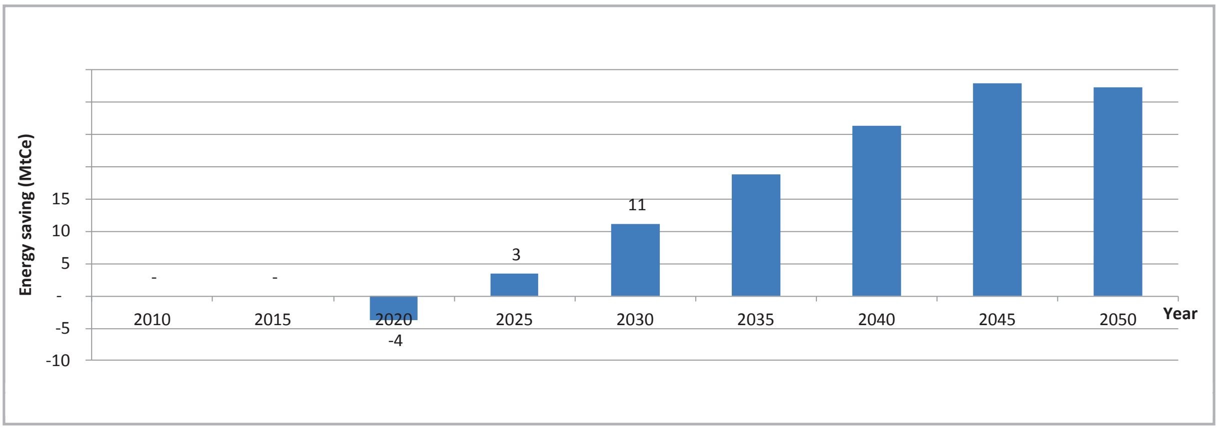


FIGURE 6-19. Energy saving from expended application



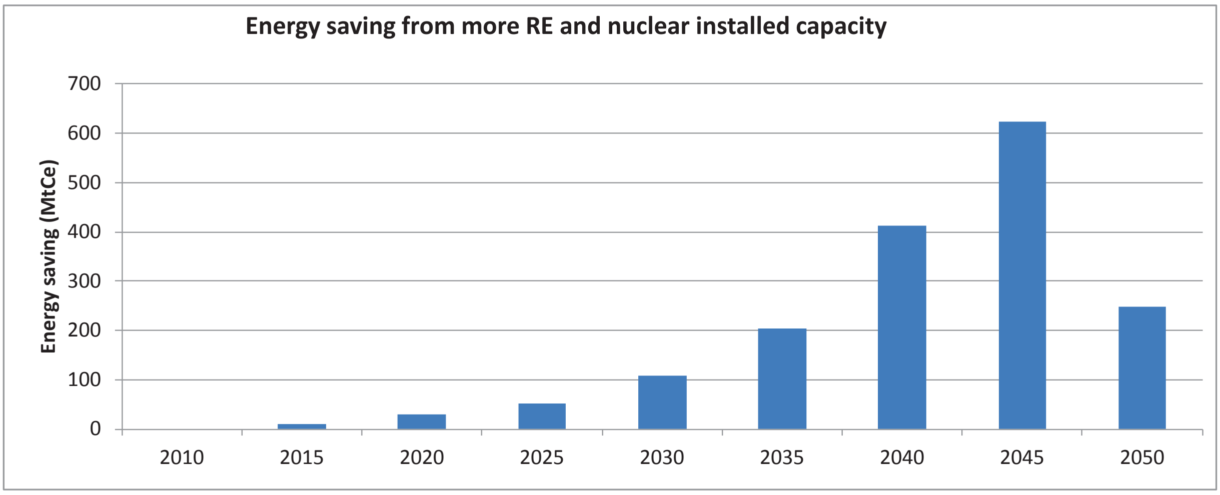
the installed capacity of cogeneration units is measured, overall consideration will be given to the increase in the fossil-fuel consumption of cogeneration units, reductions in fossil-fuel consumption resulting from the decline in the scale of pure condensing power generation units, and reductions in fossil-fuel consumption resulting from the decrease in the heating scale of pure boilers.

Model analysis indicates that the energy savings resulting from the increased installed capacity of cogeneration units (i.e., reduced fossil fuel 0) will be increased with improvement to the installed scale of cogeneration. By 2050, fossil energy consumption in the intensified energy-saving scenario may be reduced by 32 Mtce compared with the reference scenario, equivalent to saving fossil fuel amounting to 32 Mtce. By about 2045, this alternative effect will reach its peak value, and the energy savings will reach 33 Mtce (see Figure 6-19).

Energy savings resulting from improved installed capacity of renewable energy sources and nuclear power generation

After the installed capacity of renewable energy and nuclear power has been improved, it will reduce the capacity of condensing power, thus reducing the consumption of fossil fuels accordingly. Model analysis indicates that, by 2045, the energy savings resulting from the improved installed capacity of renewable energy and nuclear power will be increased to 620 Mtce. By about 2045, since the peak value of fossil fuel consumption in the reference scenario will come a little later and in the intensified energy conservation will come earlier, the reduction in fossil fuel consumption resulting from the difference between the two (the 'energy saving amount' of the power sector defined in this chapter) will rapidly decline to approximately 240 Mtce (as shown in Figure 6-20).

FIGURE 6-20. Energy saving from higher installed capacity of renewable energy sources and nuclear power generation



Waterfall chart of energy efficiency in the power sector

In summary, in the long term, the power sector in China will see the dominant role of thermal power (especially coal-fired power generation) declines and a gradual shift toward renewable energy sources and nuclear energy by 2050. This will be the general trend in the development of the Chinese power sector. At the same time, there is still potential for China's power sector to save energy and reduce fossil fuel consumption.

The analysis conducted by the research group indicates that, compared with the reference scenario, in the intensified energy-saving scenario, by 2050 the maximum 'energy efficiency' potential (defined by the research group as the potential for reducing fossil fuel consumption) will come from replacing fossil-fuel power generation and heat supply with renewable energy sources and nuclear power. Energy savings will be 248 Mtce; for improving the power generation efficiency of thermal power generation units, by 2050, there will be an energy efficiency potential of 56 Mtce, for advancing cogeneration 32 Mtce, and for improving grid efficiency 15 Mtce (see Figure 6-21). It is to be noted that, in a future age of power being dominated by renewables, the reduction of fossil fuel consumption by improving energy efficiency will be relegated strategically to a secondary position.

Therefore, from the long-term perspective, the main feature of the power sector in the future will be its transformation from existing improvements to thermal power efficiency to attempts to improve the share of zero-carbon energy, such as renewable energy and nuclear power. For Chinese decision-makers in the energy field seeking new solutions for new situations, it will be important to grasp the general trend of development in the Chinese power sector in the future and the change in the focus of work on energy efficiency work.

6.3 IDENTIFICATION OF HIOS OF THE POWER GENERATION SECTOR IN CHINA

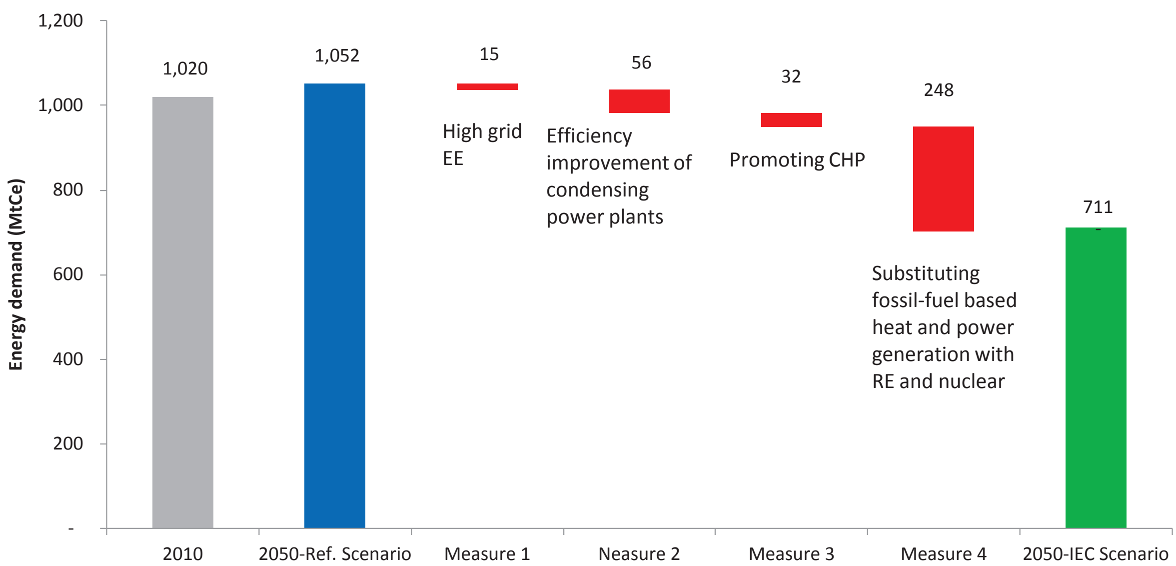
The difference between the reference scenario and the intensified energy-saving scenario in the results in the model are attributable to both technical and structural factors. The major technologies with an impact on the power sector include cogeneration (e.g. transforming pure condensing units into cogeneration units), energy conservation transformations of thermal power generation units, improving grid transmission, distribution efficiency, etc. The structural factors include reducing fossil fuel consumption, mainly including improving the share of renewable energy, developing nuclear power, generalizing natural gas power generation, etc.

6.3.1 TECHNICAL HIOS

HIO 1: Transformation of pure condensing units to realize cogeneration

The technology for transforming pure condensing turbine units to realize cogeneration is mainly applied to 125-200MW pure condensing turbine units in the power sector. The technical principle is the holing-extraction of pure condensing turbine units to enable them to serve the dual functions of pure condensing power generation and

FIGURE 6-21. **Waterfall chart of energy efficiency improvement potential in the power sector**



heat supply. (1) No change will be made to the body of pure condensing turbines. Holing-extraction is conducted through two medium-low-pressure connecting pipes, consolidating the same sides, and making use of the regulating valve and main governing valve to control the extraction parameters to enable the pure condensing power generation unit to assume the functions of cogeneration and pure condensing power generation. (2) In dual-function mode, the pure condensing mode maintains the original operating mode without a change. For operation in the form of cogeneration, in order to maintain the safety performance unchanged, a heating capacity of 150t/h and above can be achieved, thus reaching the requirements of the basic indicators of cogeneration, namely the heat-to-electric ratio: >50% and thermal efficiency: >45%. (3) The parameters of heating, heat supply and extraction after transformation comply with the requirements of the conventional heat supply.

At present, the average energy consumption of 200 MW three-cylinder three-exhaust pure condensing turbine units is approximately 355gce/kWh, while that of centralized boiler rooms is approximately 52kg/GJ. From the perspective of the technical and economic parameters of the existing investment project, investment in the transformation of the two sets of 200 MW three-cylinder three-exhaust pure condensing gas turbine units required will be RMB 16 million, achieving energy savings of 14,000 tce per year. The analysis of the *China Catalogue for Generalization of Energy Efficiency and Low-carbon Technologies (2015)* suggests that the generalization ratio of cogeneration technologies realized through the transformation of pure condensing turbine units is less than 5% at present. It is estimated by 2020 the technical generalization ratio will be 10%. During the 13th Five-year Plan period, the total investment required will be approximately RMB 1.6 billion, and China will achieve energy savings of 4 Mtce per year.

The main barriers to the transformation of generalizing cogeneration include (1) the lagging behind of the construction of urban heat supply network infrastructure. In China, thermal power plants generally belong to power generation companies, while heat supply networks are generally planned and constructed by local government and heating power companies. The enthusiasm of local government and local heating power companies for heat supply network construction is not high, and such construction is not timely, possibly impeding the development of cogeneration. (2) The heating power and power system is incomplete. Under the existing system, heat power plants and thermal power plants will bid to access the network on an equal basis. However, since the installed capacity of heat power plants is restricted by thermal load, property, etc., unit capacity will be much smaller than the scale of the existing pure condensing steam generator units. In addition, thermal power plants are usually close to urban and densely inhabited districts, and environmental protection standards will be much higher, and so will unit investment as a result. This means that combined heat and power generation and pure condensing thermal power generation units are usually disadvantageous in grid competition. (3) The generation capacity of cogeneration units is affected by heating power demand. Cogeneration units are usually designed according to the principle of 'ordering power by heat'; when the heat load demand is instable, the generation capacity will also be affected. Therefore, the problem has arisen that the economic benefits of heat power plants are affected by the instability of the heating power load and electric load. If the growth in economic development slides and the rate of operation of enterprises becomes insufficient, new changes will have to take place to heating and power demand in industrial parks, and the difficulties in guaranteeing the economic benefits of cogeneration unit will increase.

HIO 2: Comprehensive energy conservation transformation technology of coal-fired power plants

The comprehensive energy conservation transformation technology of coal-fired power plants mainly consists of the comprehensive transformation of turbine units, the in-depth recovery of residual heat from flue gas, condenser vacuum keeping, and other technologies designed to realize energy efficiencies in the operation of the power plant.

(1) Comprehensive technology for improving the performance of turbine units in thermal power plants. This technology is mainly applicable to gas turbine generator units that have been commissioned with higher energy consumption. By optimizing the body of the turbine and thermal system, analyzing equipment design and manufacturing, power plant design and auxiliary machine configuration, equipment installation and overhaul, operation and maintenance, and their mutual relations, turbine performance will be comprehensively improved. Key technologies for transformation include turbine unit performance diagnosis technology, technologies for improve turbine unit performance, technologies for improving heat-power systems and equipment, measures and methods for improving equipment overhaul, and best practice operational and maintenance measures and methods. Through improvements, the unit heat consumption rate will be reduced by 80-150kJ/kWh (mainly for the 300-600 MW class unit). After improvement, the unit can reach a higher economic level in the long term and also reduce maintenance costs and pollution emissions per unit of generation capacity.

(2) Technology of waste-heat in-depth recovery of the thermal power plant exhaust gas comprehensive optimization system. This technology is applicable to coal-fired units with an actual exhaust gas temperature greater than 120ºC. The principle of this technology is to install gas coolers at the tail flue between the air pre-heater of the power station boiler and the electric precipitator, thus reducing the flue temperature to approximately 90ºC. The recovered gas heat may heat the compensated water from 70ºC to approximately 110ºC, thus pushing out low-pressure heater steam extraction and increasing the action of the turbine. While recovering residual heat from flue gas, the system will not affect the long-cycle safe operation of the heat system. This can not only reduce the exhaust gas temperature and improve the efficiency of the unit, but also improve the efficiency of the electric precipitator and save water consumption by the desulfurizing tower. The key technologies for this transformation are mainly the design of the gas cooler, a low-temperature corrosion study of the flue gas cooler, anti-ash and anti-abrasion design of the gas cooler, heat system optimization design and control, etc. After adopting flue gas in-depth cooling technology, coal consumption for power generation will be reduced by 2-3g/kWh. Compared with traditional low-temperature economizer technologies, since the in-depth cooling effect increases energy savings by more than 30%, dust emissions will be reduced by more than 50%.

(3) Vacuum holding energy efficiency system technology of thermal power plant condensers. This technology is applicable to the generation units of water-cooled condenser systems in various specifications. Condensers deal with the exhaust steam from turbines and the heat exchange of cooling water. The fouling formed in the condenser cooling tube can not only affect heat exchange efficiency and further reduce turbine efficiency, it also easily corrodes the condenser and wearing tube, reducing the vacuum, etc., and seriously affecting the economic and safe operation of the turbine. Turbine condenser vacuum holding energy efficiency systems clean using a rubber ball and can automatically and continually eliminate the fouling of the condenser and maintain a ball collection rate of more than 95% for long periods of time. After normal operation, the cleanliness of the condenser will be improved and kept above 0.85 for long periods of time, thus improving unit performance and reducing the energy consumption of the turbine. The application of this technology can maintain the ball collection rate above 95% for long periods of time, keep all the cooling tubes of the condenser clean for a long time, avoid manual cleaning by closing down, and significantly reduce the terminal temperature difference of the gas turbine. The degree of vacuum in the condenser can be obviously improved and kept at an ideal vacuum value, and the average coal consumption of turbine will be reduced by 2-4g/kWh.

Based on an actual case from the existing project, it is estimated that by making use of the comprehensive technology for the performance of turbines in thermal power plants, by transforming five units with investments of RMB 18 million, the energy saving potential is about 54,000 tce per year. By transforming a 300 MW unit with an investment of RMB 9.6 million for the in-depth recovery technology of residual heat for the flue comprehensive optimization system of the thermal power plant, it can realize energy savings of 3900 tce per year. Through the transformation of two sets of 310 MW units with an investment of RMB 8 million in the condenser vacuum holding energy efficiency system technology of the thermal power plant, energy savings of 6000 tce per year can be achieved.

Analysis of the *China Catalogue for Generalization of Energy Efficiency and Low-carbon Technologies (2015)* indicates that the generalization share of the comprehensive technology for improving the performance of the turbine unit of thermal power plants is at present less than 10%. It is estimated that by 2020 the technology generalization rate will be 30%. During the 13th Five-year Plan, the total investment required will be approximately RMB 1 billion, producing expected energy savings of 2.1 Mtce per year. The generalization rate of the residual heat in-depth recovery technology for the comprehensive optimization system for the flue gas of thermal power plants is approximately 10%. It is estimated that by 2020 the technology generalization ratio will reach 50%. During the 13th Five-year Plan, the total investment required will be approximately RMB 7.2 billion, with expected energy savings of 3.2 Mtce per year. The generalization rate of the vacuum holding energy efficiency system technology of the condenser of the thermal power plant will be less than 3%, and it is estimated by 2020, the technology generalization share will reach 20%. During the same plan, the total investment required will be approximately RMB 3.2 billion, with expected energy savings of 1.7 Mtce per year. During the same plan as well, total investment in the generalization of the three technologies in the thermal power sector is expected to be RMB 11.4 billion, with energy savings of 7 Mtce per year.

HIO 3: Newly built unit adopts large-capacity, high-parameter coal-fired generation unit.

Ultra-supercritical power generation technology uses large-capacity, high-parameter units, which will be distinctively advantageous in efficiency, reduce coal

consumption and reduce carbon emissions. In 2010, the average gross coal consumption rate in China was 333 gce/kWh. The gross coal consumption rate of super-critical coal-fired power units with a capacity of 600 MW and above was less than 300 gce/kWh, potentially reducing CO_2 emissions by approximately 110 g/kWh. According to actually measured data, the power supply coal consumption of two sets of supercritical generation units in Shanghai Waigaoqiao Plant No.3 may be 274.7 gce/kWh, and the SO_2, NOx and dust discharged will be much lower than the national environmental protection standard. During power generation, emissions of NOx are even lower than for gas-burning thermal power units in the same conditions (Table 6-7).

HIO 4: Implement grid energy conservation transformation

In linking power transmission and distribution, the generalization of such technologies as controllable automatic capacity-regulating and voltage-regulating distribution transformers, full optical fiber current / voltage transformers, fast eddy current drives and short circuit identification-based power grid operation control, overhead ground wire insulation grounding method-based power line and energy efficiency technology, etc. will produce marked energy efficiency potentials.

(1) The controllable automatic capacity-regulating and voltage-regulating distribution transformer technology is one of the power industry's leading pieces of equipment, consuming power energy while transmitting it. Although the efficiency of transformers reaches 96.0%-99.7% due to large consumption levels and a wide range of applications, there are considerable numbers of high-energy consumption transformers still in the operation in China's electric grid, the power energy consumed being astonishing. In electric grid loss, transformer loss accounts for more than 60%. The loss of all transformers accounts for more than 4% of national generation capacity, of which the loss of the distribution transformer accounts for approximately 30% of the total loss. Therefore, reducing the energy loss consumption of transformers has increasingly become one of the key points in the energy conservation of the power system. Controllable automatic capacity-regulating and voltage-regulating distribution transformer technology is applicable to 10kV distribution networks in the power sector. This technology makes use of combined type capacity/voltage regulating switches to change the connection of each tap in the coil of the transformer and the load switch state to provide such functions as automatic capacity regulation/voltage regulation, remote negative control, three-phase active imbalance adjustment etc., to achieve energy-efficient transformer operation. Compared with the Type S11 transformer, the total loss of the operation will be reduced by 48%; compared with the Type S9 transformer, it will be reduced by 53%.

(2) Full optical fiber current / voltage transformer technology. Current transformer and voltage transformers are one of the core pieces of equipment that form the basis of smart electric grids. Traditional electromagnetic-type current transformers will not only consume a great quantity of nonferrous materials such as copper, aluminum, etc., but also great quantities of energy during operation. Compared with traditional mutual inductors, full optical fiber current sensor technology will not consume a great quantity of nonferrous metals, nor pollute the atmosphere, water, etc. This is an energy-saving, environment protecting, high-tech product and will become the alternative product to the traditional mutual inductor in the future. Full optical fiber current / voltage transformer technology will be used in large smart transformer substations. The key technologies include zero-phase position and modulated wave

TABLE 6-7. Actually measured emission performance of the ultra supercritical generation unit at Shanghai Waigaoqiao Third Power Plant

PARAMETER	UNIT	AMOUNT	NOTE
Power generation capacity	GWh/half a year	5,728	Two units: #7, #8
Coal consumption	g/kWh	274.65	
SO_2	Kg/tce	0.47	National environment protection standard: 2 Kg/tce After overhaul of unit #7, 0.17 Kg/tce
NO_x	Kg/tce	0.37	National environment protection standard: 4.5 Kg/tce; Emission of unit #8, installed with SCR; Emission of fuel gas cogeneration is 1.2 Kg/tce.
Dust	Kg/tce	0.15	National environment protection standard: 0.5 Kg/tce

(Source: January - June 2013 Report of Shanghai Waigaoqiao Third Power Plant, actually measured results)

reset double closed-loop control (negative feedback) technology, full optical fiber current transformer error and suppression technology, common optical path, differential signal demodulation technology, etc.

(3) Fast eddy current drive and short circuit identification-based power grid operation control technology. The high and low voltage transmission lines in China usually have current limiting reactors and series compensation capacitors to prevent short circuits, reduce loss of line and improve voltage quality. As the electric grid has been constantly expanded in China in recent years, the short-circuit capacity of the power system will be increased continually. The application proportion of current limiting reactors will be increased year by year. When a short-circuit fault occurs on an electric grid system, current limiting reactors can play the role of reducing the impact on electric grid equipment, but since the series connection in electric grids will produce a great quantity of heat loss, this will lead to increases in line loss and cause the loss of power energy. A set of current limiting reactors may consume several hundred thousand to millions of kWh of power energy annually. Series capacitors can solve the problems of the poor quality of the terminal voltage of the power transmission line and excessive grid loss, but restrictions such as the higher cost of series compensation capacitor technology, inconvenient maintenance, etc., make it difficult for series compensation capacitor devices to be generalized and applied on a large scale. Fast eddy current drives and short circuit identification-based power grid operation control technologies are applicable to those places where long-distance transmission lines, transformers with high leakage impedance in the power sector, or electric reactors and other energy-consuming equipment operate for long periods of time. By way of fast eddy current drive-type vacuum circuit breakers, in combination with power grid fault fast recognition technology, inputting compensating capacitors in long-distance transmission lines or current limiting reactors in cases of electric grid failure, this will reduce the power energy loss of current limiting reactors and avoid the impact of large current and high voltage surge current to series compensation capacitors during short circuits, this achieving the highly efficient operation of the electric grid.

(4) Overhead ground wire insulation grounding method-based power line and energy efficiency technology. Overhead ground wire provides security assurance in power transmission lines, but power transmission wires produce electromagnetic induction and form induced currents between ground wires and between ground wires and the earth. Calculated according to the existing design standard in China, among 110kV, 220kV and 500kV power transmission systems, the energy loss of overhead ground wires will be 3,700 kWh/km per year, 14,400 kWh/km per year, and 28,400 kWh/km per year respectively. By taking the line scale of the south power grid, the power energy loss of overhead ground wires each year is approximately 1.67 billion kWh, equivalent to the consumption of 540,000 tce. Overhead ground wire insulation grounding method-based power line and energy efficiency technology will change the earthing mode of ordinary ground wire and optical fiber composite overhead ground wire from tower-to-tower grounding to insulation single point grounding, thus cutting off the current path between grounding wire and earth and reducing the energy loss generated by induced current. At the same time, through the effective control of voltage, it will reduce the potential safety hazard.

From the perspective of the operating effects of the existing project, controllable automatic capacity-regulating and voltage-regulating distribution transformer technology is introduced to conduct intelligent transformation. An investment of RMB 14 million can realize energy savings of 1800 tce per year. Full optical fiber current/voltage transformer is used for the intelligent transformation of high-voltage equipment, and an investment of RMB 2 million can realize energy savings of 1000 tce per year. Fast eddy current drives and short circuit identification-based power grid operation control technology are used, and an investment of RMB 3 million can realize energy savings of 3800 tce per year. For AC transmission power efficiency technology based on overhead ground wires, an investment of RMB 22,000 can realize energy savings of 150 tce each year.

Analysis of the *China Catalogue for Generalization of Energy Efficiency and Low-carbon Technologies(2015)* indicates that the share of generalization in controllable automatic capacity-regulating and voltage-regulating distribution transformer technology in 2006 was less than 1%; it is estimated that by 2020 that the rate will be 5%. During the 13th FYP period, the total investment required will be approximately RMB 5.2 billion, with expectations of energy savings of 670,000 tce per year. The generalization rate of the full optical fiber current/voltage transformer is approximately 1%, and it is estimated that by 2020 the generalization rate of the technology will be 50%. During the 13th Five-year Plan period, the total investment required will be approximately RMB 1.8 billion, with expectations of energy savings of 1 Mtce per year. The generalization rate of the fast eddy current drive and short circuit identification-based power grid operation control technology will be less than 1% and will be 40% by 2020. During the

13th Five-year Plan period, the total investment required will be approximately RMB 500 million, with expectations of energy savings of 1.90 Mtce per year. The generalization rate of overhead ground wire insulation grounding method-based power line and energy efficiency technology will be approximately 1%, with expectations that by 2020 the generalization rate of the technology will be 30%. During the 13th Five-year Plan period, the total investment required will be RMB 250 million, with expectations of energy savings of 810,000 tce per year. During the 13th Five-year Plan period, the estimated investment required for improving power transmission and distribution efficiency will be more than RMB 7.7 billion, with energy savings of more than 4.38 Mtce per year.

6.3.2 STRUCTURAL HIOS

HIO 1: Speed up the development of renewable energy

Renewable energy power generation will not emit any carbon dioxide during power generation and is characterized by 'zero carbon power'. At the same time, renewable energy sources do need manpower to prepare 'fuel'. Once the power generation facility has been constructed, power can be used continuously free of charge and is characterized as 'near zero cost' energy. In the context of responding to climate change, renewable energy sources are considered to be the alternative energy source with the greatest potential. In 2011, at the United Nations General Assembly, the United Nations Secretary-General Ban Ki-moon declared the goal of 'Sustainable Energy for All', i.e.: (1) by 2030, the whole world population should have a modern energy service; (2) the speed of improving energy efficiency should be doubled; (3) the share of renewable energy in the energy used globally should be doubled.

In China, the share of renewable energy in primary energy consumption has been made one of the compulsory objectives of Chinese economic and social development. The latest objective is that the proportion of renewable energy in the consumption of primary energy will be increased from 12% in 2015 to 15% in 2020. In order to accomplish this objective, the Chinese government has drawn up an ambitious renewable energy source development plan and promoted realization of the objective by such measures as government subsidies, implementing quotas for renewable energy, etc.

The barriers faced by renewable energy source power generation in China include: (1) the greater cost of unit installed capacity. At present, the unit installed cost of renewable energy is higher than coal-fired power, and Chinese enterprises have not fully mastered some core technologies. Therefore, power generation pricing has become the main barrier to whether large-scale generalization can be implemented in the future. (2) The capacity of the electric grid to digest sources of renewable energy is relatively limited. At present, China's electric grid has insufficient capability to digest renewable energy sources, leading to problems of wind abandoning, water abandoning, light abandoning, etc. In minority areas, wind abandoning and light abandoning have even reached levels of one-third. The insufficient absorption capacity of the electric grid has already become the most important bottleneck in the development of renewable energy sources.

HIO 2: Scale development of nuclear power

International experience has shown that nuclear power is one of the most important low-carbon energy sources, and it has assumed an important position in the power structure of developed countries. Through more than three decades of development, China has basically grasped the second generation of pressurized water reactor power generation technology. China's energy development strategy sees the safe development of nuclear power as one of its important objectives in energy development. At present the generation capacity of nuclear power in China only accounts for 2-3% of national generation capacity. In order to realize the scale development of nuclear power, China has already begun to construct the second generation and a half and the third generation of pressurized water reactor nuclear power stations. Today, China has become the country with the most nuclear power plants under construction in the world. It is expected that nuclear power will play a more important role in Chinese energy structure in the future.

Barriers faced by China in the development of nuclear power include: (1) Investment in unit initial installed capacity will be very high. At present the unit installed cost of nuclear power is obviously higher than for coal-fired power. Especially in the case of third-generation pressurized water reactor technology, Chinese enterprises are still at the construction phase of demonstration projects, and the initial investment will be relatively higher. (2) Coastal factory sites are insufficient, and the merits of onshore nuclear power initiation are still in dispute. Concerning nuclear power safety, there are still different voices in China. Especially after the Fukushima Daiichi nuclear disaster, there are still some debates on whether the construction of nuclear power stations should be initiated in the inland areas of China.

HIO 3: Develop natural gas power generation

Natural gas power generation units are characterized by quick peak regulation responses and relatively low carbon dioxide emissions compared with coal-fired units. Natural gas power generation, which uses a low-carbon fossil fuel, not only helps carbon dioxide emission reduction, but also undertakes the important task of peak re-

gulation in power grids when renewable energy sources develop on a larger scale in the future, when the installed power generation capacity of natural gas in China will enter a stage of rapid growth.

The barriers faced to the development of natural gas power generation include: (1) the cost of unit installed capacity is relatively high. At present, Chinese enterprises have not fully mastered the design and manufacturing technology of the heavy-duty gas turbines used in power generation. The unit installed cost of gas turbines is higher than for traditional coal-fired power units. The higher price hinders the large-scale generalization of natural gas power generation units. (2) The price of natural gas is still high. Sources of natural gas are scarce in China, and the price of imported natural gas is also very high. Higher initial investment and higher fuel costs make it difficult for natural gas power generation and conventional coal-fired power generation to achieve economic competitiveness in the power market. (3) The market-oriented reform of power has not yet been completed. At present, the grid companies still determines the generating units for meeting the grid load based on the traditional economic dispatch model. In this mode, natural gas power generation, mainly for peak regulation, is difficult to obtain a higher price for in accordance with the cost of the peak load. This income is obviously on the low side, and the economic benefit is very poor.

6.4 POLICY RECOMMENDATIONS

In order to promote further advance power technology with high opportunities to affect energy efficiency and play larger role in power generation, the research group put forward the following suggestions:

6.4.1 RECOMMENDATION 1: ENCOURAGE THE PROMOTION OF COGENERATION ACCORDING TO CIRCUMSTANCES

Encourage cities and industrial parks and zones with sufficient conditions to construct cogeneration units and encourage coal-fired units to implement the transformation of cogeneration. Encourage local government to develop cogeneration and formulate preferential policies in the areas of initial investment, operation and maintenance, infrastructure construction, etc. In areas where cogeneration development plans have been formulated, local government should formulate regional heat-supply pipe network development plans appropriate to the development scale of cogeneration units to enable uses based on centralized heat supply to adopt it to the full. Further promote heat supply system reform, perfect heating power pricing mechanisms, remove heat supply subsidies and adjust heat supply charging modes.

6.4.2 RECOMMENDATION 2: ENCOURAGE COAL-FIRED PLANTS TO IMPROVE POWER GENERATION EFFICIENCY

Encourage coal-fired power plants to establish enterprise energy management systems and formulate energy conservation and energy efficiency improvement plans on the basis of energy audits and awareness of own resources. Encourage competent department for power generation or power association to implement energy efficiency benchmarking for power generation enterprises and create a culture of competition in which power enterprises go after 'energy efficiency pacemakers'. Implement total carbon emissions control and carbon emissions trade in power generation enterprises through carbon emissions trade; encourage power generation enterprises to improve energy efficiency and obtain the economic benefits of carbon dioxide emissions reductions through trading.

6.4.3 RECOMMENDATION 3: STUDY OF NEW-GENERATION HIGH-PERFORMANCE AND LOW-COST POWER GENERATION TECHNOLOGY

Accelerate efforts regarding the research and development of new generations of power technology and make key breakthroughs in the core technology of large wind power units, heavy-duty gas turbine technology for power generation, third-generation nuclear power technology, high-temperature gas cooled reactor technology, etc. Encourage the piloting and demonstration of advanced technology and strive to realize the localization of these core technologies in the design, manufacture and operation early, thus greatly reduce costs.

6.4.4 RECOMMENDATION 4: ENCOURAGE THE ENERGY CONSERVATION TRANSFORMATION OF THE POWER GRID AND THE DIGESTION OF RENEWABLE ENERGY

Encourage grid enterprises to accelerate the implementation of energy conservation transformation and intelligent transformation, and improve the automation and digitalization of the links between grid trading, transmission and distribution, scheduling, charging electric fee, etc. while reducing grid line loss. The development of the electric grid should take the digestion of renewable energy sources as the important development objective, enhance the construction of cross-regional transmission lines and improve the capability of the interconnection between regional grids. Improve the predictive ability of electric grids regarding renewable energy power genera-

tion and enhance the power generation capacity of peak regulation in the power grid to ensure that the share of renewable energy power generation in gross power generation be improved steadily.

6.4.5 RECOMMENDATION 5: SPEED UP THE REFORM OF THE POWER SYSTEM

China has already drawn up a new roadmap for the reform of the power system. This calls for the spirit of the central government to be followed by accelerating the market-oriented reform of the power sector, breaking the monopoly in such links as power generation, scheduling, transmission and distribution, sales, etc. and speeding up marketization, accelerating the pace of adjustment in key fields such as power pricing, power supervision and management, pollutant emissions, greenhouse gas emissions, etc., to encourage China's power sector to move in an high-efficiency, clean, low-carbon direction.

7

CHAPTER

CONCLUSIONS AND DISCUSSION

Zhiyu TIAN

7.1 CONCLUSIONS

Energy efficiency and conservation efforts, either through improved energy efficiency or energy intensity technically, or through structural shifts from energy-intensive activities to more service-oriented activities, both contribute greatly to upgrading the quality of economic growth, alleviating environmental pressures and improving energy security. The Chinese government has attached great importance to energy efficiency and conservation in past decades, setting mandatory reduction targets for the energy intensity of GDP in its economic and social development plans, broken down into provincial, municipal, county and energy-intensive enterprises. Remarkable progress has been made in technical energy efficiency, as well as improvements in nationwide energy efficiency and competitiveness. By 2015, energy use per unit of GDP declined by 18.4% compared to 2010, far exceeding the set target of 16% for the 12th FYP. From 2010 to 2015, energy efficiency and conservation allowed China to avoid the equivalent of 865 Mtce of energy use, equivalent to a reduction of 1.82 billion tons of CO_2 emissions. Efforts in achieving energy efficiency and conservation in China contributed greatly to sustainable transformation globally, accounting for more than half of the world's entire energy savings in the past thirty years.

Energy efficiency is the most important mechanism through which countries can act to mitigate climate change in the short- to long-term, especially in countries experiencing fast industrialization and urbanization like China. Over the next few years, China will continue to draw up various energy-efficiency programs within its economic and social development strategies in order to achieve the new target to reduce energy intensity by 15% from 2015 to 2020, as well as to cap primary energy consumption by around 5 Gtce by 2020. In 2015, China released its INDCs, in which it promised that its CO_2 emissions will reach peak value in around 2030 and that it will strive to reach this peak value as early as possible, that CO_2 emissions per unit of GDP will decrease by 60% to 65% against 2005, and that the share of non-fossil fuel energy in primary energy consumption will reach about 20%. To act on energy efficiency and conservation, China is not only driven by its domestic need for sustainable development in ensuring its economic prosperity, energy security and environmental quality, but also by its sense of responsibility to engage fully in global governance and promote common development for all human beings. In accordance with its pledge to cut greenhouse gas emissions, China will also institute a revolution domestically in energy production and consumption for 2030 and 2050, with improving energy efficiency being an important pillar of the strategy.

Using the LEAP model and the C-CGE (China - Global Energy) model, in addition to various case studies across industry and the building, transportation and power sectors, it was concluded that China could achieve its INDC targets by intensifying its energy conservation and low-carbon transformation efforts. Compare to the reference scenario, carbon emissions in 2030 could be 15% lower if China is to achieve its emissions peak around 2030. Under the intensified energy-saving scenario, on the other hand, carbon emissions in 2030 could be 27% lower compared to the reference scenario. Energy efficiency and conservation play a vital role in both scenarios in achieving the climate pledge, contributing about three quarters of total emissions reductions.

As the low-hanging fruit for energy efficiency has been gathered in recent years, the report provides detailed insights into the future options for energy efficiency. By conducting comparative analyses and sensitivity analyses of the reference scenario and the intensified energy saving scenario until 2050, HIOs for energy efficiency from both the technical and structural perspectives have been identified. In total, there are 26 HIOs in the industrial, building, transportation and power sectors, of which sixteen are technical and ten structural. Under the joint effects of technical improvements and structural optimization, these HIOs together can realize energy savings of over 2 Gtce in 2050.

In the industrial sector, four technical and three structural HIOs are identified, which will result in energy savings of over 1 billion tce in 2050. The selected technical HIOs included industrial waste heat recovery technology, advanced industrial combustion/calcination technology, high-efficiency environment-friendly industrial boilers, and raw material route-based process adjustment and energy use optimization. The four technical HIOs are estimated to save energy amounting to 580 Mtce in 2050, of which nearly 200 Mtce will be saved by industrial waste heat recovery technology. The structural HIOs included 'de-capacity' and the transformation development of energy-intensive industries, industrial 'eco-link' development mode and a subversive industrial production technical revolution. In 2050, the three structural HIOs are estimated to save energy amounting to about 500 Mtce, of which nearly 200 Mtce is saved by 'de-capacity'.

In the building sector, four technical HIOs and one structural HIO are identified, which will contribute energy savings of over 700 Mtce in 2050. Energy savings in the building sector are mainly contributed by technical HIOs, including promoting passive housing, popularizing high energy efficient equipment, carrying out deep-level energy conservation retrofits to existing buildings and using low-grade industrial waste heat for heating. The first three HIOs contribute respectively energy sa-

vings of 220 Mtce, 200 Mtce and 120 Mtce in 2050. The structural HIOs mainly involve promoting building industrialization. Energy savings in 2050 will stand at 30 Mtce. Moreover, building industrialization can save materials, indirectly lowering energy consumption in the industrial sector.

In the transportation sector, four technical and three structural HIOs are identified, which will contribute energy savings of 650 Mtce. Technical HIOs include upgrading the fuel economy of trucks, improving the fuel economy of light passenger vehicles, developing and popularizing battery electric and plug-in hybrid electric vehicles, and increasing the electrification of the railways. In 2050, energy savings from the above HIOs respectively will be 45.94 Mtce, 12.39 Mtce, 49.22 Mtce and 11.28 Mtce. Structural HIOs include improving the share ratio of public transport, improving the share of railway use and promoting vehicle sharing. In 2050, energy savings from the above HIOs respectively will be 14.85 Mtce, 8.06 Mtce and 0.3 Mtce.

In the power sector, four technical and three structural HIOs are identified, which will contribute energy savings of 340 Mtce in 2050. Technical HIOs include the transformation of pure condensing steam turbine units to realize cogeneration, comprehensive energy conservation transformation technology for coal-fired power plants, the adoption of large-capacity and high-parameter coal-fired generation units for newly built units, and the implementation of power grid energy-saving technological transformations. Structural HIOs include accelerating the development of renewable energy power generation, promoting the scale development of nuclear power and developing natural gas power generation. The biggest fossil fuel energy saving potential in the power sector under the intensified energy-saving scenario in 2050 comes from the replacement of fossil fuels with renewable energy and nuclear power for power generation and heating, which can save energy by 248 Mtce. Improving the power generation efficiency of thermal power units can contribute energy savings of 56 Mtce, popularization of cogeneration can contribute 32 Mtce in energy savings, and improvements to power grid efficiency contributes 15 Mtce.

7.2 DISCUSSION

Achieving energy and CO_2 reductions under the intensified energy-saving scenario will require overcoming a multitude of barriers to the full deployment of HIOs that exist in the building, industry, transport and power sectors. Overcoming these barriers will require the sustained and targeted support of China's government, its enterprises and its society at large, including the implementation of policies that target common actionable approaches, including aligning government policies and business interests with the strategic goals of energy efficiency and conservation; prioritizing structural adjustment and irrational demand reduction as critical drivers to make the energy transformation happen in an affordable and efficient manner; promoting electrification and reforming the electricity sector to support clean and low-carbon supply options; and spurring technological innovation and integrative design to minimize investments in smart and shared infrastructure. Besides, specific attention should be paid to sectoral high impact opportunities, including:

In the industrial sector, widening the channels for enterprises to acquire information and application in cases of energy-saving technologies; improving standard systems related to energy saving production processes, technologies and equipment; removing system and mechanism barriers across departments and industries; and establishing an institutional environment that is favorable to the optimization and upgrading of industrial structure and to improving industrial competitiveness. In the building sector, strengthening capacity building to promote passive housing; improving the minimum requirements for the energy efficiency standards of appliances; exploring deep-level energy conservation retrofits for existing buildings; and reinforcing the planning of industrial waste heat for heating in cities and towns. In the transportation sector, boosting the transformation and upgrading of transportation sector management; quickening the pace of the reform of railway marketization; periodically releasing and updating fuel economy standards in a timely fashion; expediting the construction, investment and financing of public transport infrastructure; and continuing with R&D and the promotion of advanced technology. In the power sector, encouraging cogeneration promotion according to local circumstances; improving power generation efficiency in coal-fired power plants; exploring new-generation, high-performance and low-cost power generation technologies; boosting energy conservation transformation and renewable energy absorption of power grids; and speeding up power system reforms.

The analyses in this report have shown that China could fulfill its pledge in its INDCs by achieving an earlier emissions peak by around 2025. It can do this by seizing high impact opportunities for energy efficiencies in the industrial, building, transportation and power sectors. However, this will not be achieved without a concerted set of market actions and policy interventions, as well as deep reforms in almost every aspect of a developing country such as China, which is still making the transition from a central-planned economy to a market-oriented economy. This report has highlighted the energy efficiency

and conservation opportunities from both technical and structural perspectives, but a high degree of uncertainty remains when it comes to fully tapping into the potentials available, such as rebound effects from restructuring patterns of consumption, lower-than-expected technical progress in renewable energy, a social backlash in nuclear power deployment, and vexed adjustments to interests caused by institutional reforms. This report has laid the foundation for analyzing high impact opportunities for energy efficiency in China. In terms of future areas of research, regional and sectoral analyses should be deepened, with a focus on cross-regional and cross-sectoral opportunities, in light of emerging technologies related to energy use, innovative commercial patterns and the institutional dividends from reforms to energy pricing, electricity dispatch and industrial governance. As China's economy enters a new normal phase with a lower GDP growth rate, attention should also be paid to the potential contributions of energy efficiency and conservation to economic growth.

	AUTHORS AND EDITORS
	Dr. Quan Bai is the Executive Director and Research Professor at the Energy Efficiency Center of Energy Research Institute (ERI) of National Development and Reform Commission (NDRC), China. He is specialized in of energy economics, energy efficiency, climate change and energy technology policies and strategies.
	Mr. Guanyun Fu is a researcher at the Energy Research Institute (ERI) of NDRC, China. His research mainly focuses on energy consumption in the Chinese industrial sector and energy efficiency policies assessment.
	Ms. Jingru Liu is a senior researcher of Energy Research Institute (ERI) of National Development and Reform Commission (NDRC), China. She is specialized in policy Research of energy economics, energy efficiency and energy technology.
	Dr. Qingbing Pei is a researcher at the Energy Research Institute (ERI) of National Development and Reform Commission (NDRC), China. He is specialized in energy efficiency analysis and energy conservation policy.
	Mr. Zhiyu TIAN is the Deputy Director and a senior researcher at the Energy Efficiency Center of Energy Research Institute (ERI) of NDRC, China. His research focuses on the governance and policy issues related to energy efficiency and low-carbon development.
	Ms. Yuyan Weng is a Ph.D. candidate at the Institute of Energy, Environment and Economy of Tsinghua University in China. Her research focuses on energy policy, low carbon economic transformation, and energy-economic modelling.
	Mr. Huawen Xiong is the Deputy Director and a senior researcher at the Energy Efficiency Center of the Energy Research Institute (ERI) of NDRC, China. His key expertise includes energy efficiency strategies planning, especially policies, technical and economic evaluation for the industrial sector.
	Dr. Wenjing Yi is a researcher at the Energy Research Institute (ERI) of National Development and Reform Commission (NDRC), China. She specialises in the policy research of energy efficiency and energy outlook of transportation sector.
	Mr. Jianguo Zhang is a senior researcher at the Energy Research Institute (ERI) of National Development and Reform Commission (NDRC) in China. His main expertise area is energy efficiency policies, especially in building sector.
	Prof. Zhang received his Ph.D. in Systems Engineering at Tsinghua University in 1997. Dr. Zhang is currently a professor of energy management and climate policy and director of Institute of Energy, Environment & Economy, Tsinghua University.
	Dr. Sheng Zhou is an associate professor at Institute of energy environment and economy of Tsinghua University in China. His research focuses on energy model development and scenario analysis, climate change and carbon market.
	Dr. Xianli Zhu is a Senior Economist at the Copenhagen Centre on Energy Efficiency, UNEP DTU Partnership. She specialises in policies and measures for energy efficiency and climate change mitigation in developing countries.

This report on *Enhancing Energy Efficiency in China: Assessment of Sectoral Potentials* uses energy and economic model to assess the potential for further energy efficiency improvement in the transport, building, industry, and power sectors. For each sector, the study identifies key high impact opportunities (HIOs) for energy efficiency improvement. Moreover, it also identifies the barriers for the realisation of the HIOs in each sector and offers a set of recommendations on how to address these barriers.

This publication forms part of China and India Energy Efficiency Series. Other titles in the series include:

Best Practice and Success Stories on Energy Efficiency in China	Best Practice and Success Stories on Energy Efficiency in India
	Enhancing Energy Efficiency in India: Assessment of Sectoral Potentials
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ISBN: 978-87-93458-16-1

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