Chapter 2
Low Carbon Energy Systems in China: Visioning Regional Cooperation Through the Belt and Road

Zhu Yuezhong, Tian Zhiyu, Liu Jianguo, Chao Feng and Liang Qi

2.1 Introduction: Economic, Energy and Emission Profile

In 2014, China's gross domestic product (GDP) exceeded USD 10 trillion[1] and the per capita GDP approached USD 8,000 (2015a). From 2012 onwards, the economic growth rate steps into a new stage within 7–8 % after a high-speed development with nearly 10 % annual growth in the past 30 years. It marks that the form of economic growth has shifted from the extensive to the intensive type; and the latter type pays more attention to quality and efficiency, which is expected to be the "new normal". Under this background, the energy sector, the underpinning of the economic development, also exhibits new signs such as slowing energy consumption growth, narrowing energy supply and demand gap, initial energy mix adjustment and accelerated decline of energy intensity and carbon intensity.

2.1.1 Trends of Economic Growth and Energy Consumption

China's energy consumption entered into a high-growth phase in the new century with the acceleration of industrialization and urbanization. In 2005, the total primary energy consumption hit 2.36 billion tons of coal equivalent (tce), a net

[1]In 2014, China's GDP reached RMB 64.6463 trillion, about USD 17.49796 trillion, according to the official exchange rate.

Z. Yuezhong (✉) · T. Zhiyu · L. Jianguo · L. Qi
Energy Research Institute of National Development and Reform Commission, Beijing, China
e-mail: zhuyuezhong@eri.org.cn

C. Feng
China University of Mining and Technology, Beijing, China

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Table 2.1 China's energy consumption elasticity coefficient in different times

	GDP growth (%)	Energy consumption growth (%)	Elasticity coefficient of energy consumption
1978–1980	7.7	2.7	0.35
1980–1985	10.7	4.9	0.46
1985–1990	7.9	5.2	0.66
1990–1995	12.3	5.9	0.48
1995–2000	8.6	2.1	0.24
2000–2005	9.8	10.2	1.04
2005–2010	11.2	6.6	0.59
2010–2013	8.2	4.9	0.6

Source NBS (2015)

increase of 61.2 % compared with that in 2000. The incremental energy consumption during the 10th Five-Year Plan (FYP) period exceeded the increment combined of the past two decades, creating the fastest five-year increase since the reform and opening up in 1978 (Table 2.1). In the 11th FYP period, in order to improve energy efficiency, the Chinese government set a target of cutting energy intensity by 20 %, owing to a double-digit GDP growth in this period, the national energy consumption still climbed to 3.25 billion tce in 2010,[2] and a net annual increase of nearly 180 million tce was also observed (Fig. 2.1). It is noteworthy that the annual energy consumption growth slowed down during 2012–2014 against the background of declining GDP growth to below 8 % since the 2008 global financial crisis and especially 2010. In 2014, the energy consumption growth even registered a decade-record low of 2.2 % (2015b).

In the march towards industrialization, the economic growth is closely linked to industrial development, with the share of industrial contribution to the increase of the GDP as high as 61.6 % in 1994 and 38.3 % even in 2014. As a result, the economic growth and the industrial added value growth exhibit almost the same trend to some extent, and the statistics also show that high GDP growth is observed when the industrial added value increases more rapidly, and GDP slows down when industrial growth rate declines even more drastically (Fig. 2.2). Considering the energy consumption per unit of GDP in the industrial sector is 5–8 times that of the service and agriculture sectors, industrial slowdown implies significant decrease of demand for energy and weak dependence of economic on energy.

[2]Currently, the combined energy consumption in the country is 15 % more than announced by the National Bureau of Statistics (NBS), mainly due to differences in coal consumption statistics. China's national energy consumption in 2014 was adjusted to 4.26 billion tce, an increase of 2.2 % over 2013, according to the statistical communiqué released on February 26, 2015. Based on this, the energy consumption in 2013 is estimated to total 4.17 billion tce. However, as the latest statistical communiqué does not cover energy consumption of the last 10 years, the energy profile described hereof rests on previous statistics.

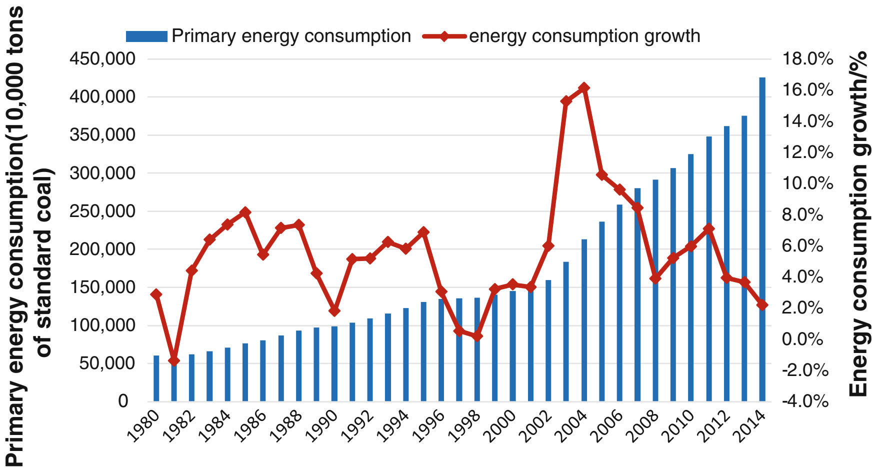

Fig. 2.1 Primary energy consumption and growth trends (1980–2014). *Source* NBS (2015). *Note* Data about primary energy consumption and growth in 2014 are sourced from the latest statistical communiqué, while data about 2013 and prior years still follow the previous statistics

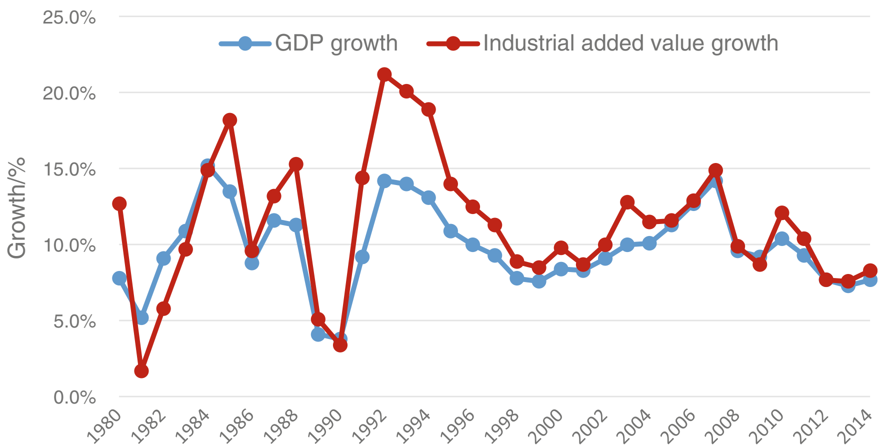

Fig. 2.2 Growth of GDP and industrial added value (1980–2014). *Source* NBS (2015). *Note* 2014 is above-scale industrial added value growth

Energy consumption elasticity coefficient is a measure of the relationship between economic growth and energy consumption. A great value of the coefficient means high economic dependence on energy, and vice versa. China's energy consumption elasticity coefficient rose from 0.42 to 0.93 during the 10th FYP period, and even achieved high values of 1.53 and 1.6 in 2003 and 2004, respectively. The average energy consumption elasticity coefficient during this period was 1.04, indicating highly dependence of economic on energy consumption. Though this dependence remained during the 11th FYP period, the coefficient successfully

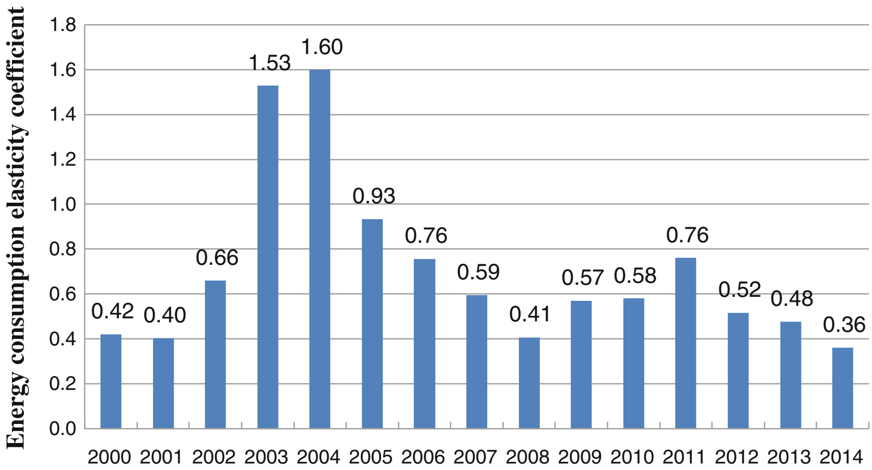

Fig. 2.3 Energy consumption elasticity coefficient (2000–2014). *Source* NBS (2015)

fell to 0.59 owing to the initiative of energy conservation and emission reduction. Post-2012 an obvious reduction in the economic and social dependence on energy was witnessed, accompanying the economic slowdown, especially in the secondary sector. The energy consumption elasticity coefficient read 0.52 and 0.48 in 2012 and 2013 respectively and only 0.36 in 2014 (Table 2.1 and Fig. 2.3).

2.1.2 Remission of Energy Supply Pressure and Alleviation of Supply-Demand Contradiction

Currently, an encouraging phenomenon is achieved that with the shift to medium-and high-speed economic growth, the energy supply-demand gap is gradually narrowing and the short-term oversupply happens in certain fields. These achievements mainly owe to the extensive energy infrastructure construction for nearly three decades, involving the large-scale development and utilization of wind and solar energy; as well as the beginning of taking effect of policies for sustainable development policies covering energy conservation and emission reduction. Preliminary statistics show a negative 2.9 % growth of the national coal consumption in 2014 over a year earlier and a 7.5 % decline in the coal consumption of major power generation companies. Meanwhile, the power consumption growth was only 3.8 %, also the lowest level in recent decade. In contrast, the verified coal production capacity has exceeded 5.5 billion tons and is expected to far exceed the demand in 2020, according to the coal consumption target of 4.2 billion tons. In 2014, China's installed power capacity attained 1.36 billion kW, ranking first in the world. However, the average operating time of power generation facilities and thermal power generation facilities shortened significantly to only 4,286 and 4,706 h, respectively, even the lowest levels since 2000. The symptom of over-supply in power sector begins to emerge.

In summary, coal and power supply will be surplus to demand; the oil supply situation will be greatly improved with the fell of international oil prices, given the large-scale imports of petroleum and natural gas due to resource endowments. Non-fossil energy supply continues to increase. As a whole, the contradiction between energy supply and demand has been greatly alleviated, and tends to ease off with economic development, regardless of energy demand growth.

2.1.3 Initial Success of Energy Mix Adjustment and Rapid Development of Efficient and Clean Energy

All along, the proportion of coal in the primary energy consumption reached about 70 % in China, which also contributes to serious environmental pollution and high greenhouse gas (GHG) emissions. From 2007, this proportion began to decline, owning to the rapid development of renewable energy sources. According to statistics, with the growing of the scale of renewable energy and nuclear energy, the proportion of non-fossil energy consumption continues to rise, increasing from 6.4 to 11.1 % during 2000–2014. In specific, there were 22 nuclear power units in the nationwide service in 2014, forming an installed capacity of 20.1 million kW. Hydropower, with an installed capacity of about 300 million kW, contributed an annual generating capacity of 1 trillion kWh. The installed capacity of wind and solar power surpassed 90 and 30 million kW respectively, accounting for 150 and 25 billion kWh of power annually. In addition, the total installed capacity of biomass and geothermal power exceeded 9.2 million kW, contributing a generation capacity of 35 billion kWh. China has achieved initial success in energy mix adjustment. At the same time, the increment of coal consumption decreased faster, the average annual increment has been down from 250 Mt during 2003–2011 to 70 Mt during 2012–2014. The coal consumption has been decreased 100 Mt in 2014, and 140 Mt in the first half 2015. The International Energy Transformation Forum held in November 2015 set a high value on the efforts made by Chinese government over the past years in advancing the transition from a fossil fuel based to a non-fossil fuel based energy system. Suzhou Declaration of the International Forum on Energy Transitions said, China's great achievements in development of wind, solar photovoltaics and solar thermal energy applications; and the experience that China has gained in maintaining a consistent policy environment, attracting private sector investments and establishing its renewable energy industry (2015c).

2.1.4 Growing Demand for High-Quality Energy and Dependence on Oil and Gas Imports

The proposals of the 13th FYP for national economic and social development approved by the fifth plenary session of the 18th CPC Central Committee made it clear that by 2020 to build a moderately prosperous society, therefore the average annual economic growth of China will be more than 6.5 % from 2016 to 2020 (2015d). To support high-speed economic growth, satisfy people's increasing demand for energy and meet the requirements of high quality environmental, during the 13th FYP, China's total energy consumption, especially high-quality energy consumption will increasing. In order to cope with smog, many provinces in China invariably take natural gas as a preferred option for improving environmental quality. Natural gas penetrates to the urban heating and transport sectors, in addition to the original power generation and chemical sectors. Corresponding data shows that China's consumption of natural gas was 24.5 billion m^3 in 2000, 167.6 billion m^3 in 2013 and 180 billion m^3 in 2014, providing an annual increase of 16 %, much higher than that of energy consumption over the same period (7.6 %). As the domestic production lagged far behind the growing demand, the dependence on natural gas imports was on the rise, even to 32.2 % in 2014. In the foreseeable future, in consideration of the strategic importance of natural gas and the difficulty in increasing reserves and production, the rising trend will continue. Unless breakthroughs in alternative fuels and technologies are sought, China will probably become more dependent on foreign oil. A new normal can be expected that towards 2030, the dependence on international market is expect to rise particularly for natural gas due to domestic increasing high-quality energy demand.

2.2 Policies and Achievements of Low-Carbon Energy System Development

2.2.1 Policy Initiatives

The development of a low-carbon, green growth momentum in China's energy industry, partly owed to the new changes under the new normal, and more importantly, benefited from effective policies and measures over the past years.

2.2.1.1 Strengthening Measures to Improve Energy Efficiency

The Chinese Government has always attached high attention to energy conservation and emission reduction and incorporated it into the macro policy since early 1980s. In 2006, energy conservation and emission reduction, as binding targets, entered into the 11th FYP for national economic and social development. In the following five years, the targets were upgraded to "cutting the energy intensity by 16 %, carbon intensity by 17 %, and emission intensity of major pollutants by 8–10 %" and published in the 12th Five-Year Plan for National Economic and Social Development (2011a). Afterwards, the comprehensive work plan for energy conservation and emission reduction during the 12th five-year plan period (2011b) and the 12th Five-Year Plan for Energy Saving and Emission Reduction (2012) were unveiled in September 2011 and August 2012, respectively, deploying the tasks, priorities and measures in detail. To ensure the accomplishment of targets, the Chinese Government issued the 2014–2015 Action Plan for Energy Conservation, Emission Reduction, and Low-carbon Development in 2014, making arrangements for the work in the last two years of the 12th FYP period (2014a). According to statistics, the Chinese Central Government invested more than RMB 110 billion in this field in the previous three years (ERI 2009; Xue and Zhao 2015).

During the 11th and 12th FYP Period, on the basis of the state goals for energy conservation and emission reduction as well as local economic development level, industrial structure adjustment potential, technical research and development capability and resource endowment etc., provincial governments puts forward the energy-saving target of various regions (Table 2.2). In the meantime, the central government actively explores the market-based mechanism to reduce emission. As a result, 7 pilots of carbon trade had been started since June, 2013; and the Interim Procedures for Management Rules on Emission Permits Trade was released on December, 2014; which established a basic for the state emission trading market. Meanwhile, provincial governments also strive to be members of "low-carbon cities" by making plans and setting up goals for local low-carbon development. Currently, 6 provinces and 36 cities have been selected to be the low-carbon pilots in China.

Table 2.2 Energy-saving target of various regions during the 11th and 12th Five-Year Plan Period

Regions	Reduction of energy intensity (%)	
	Target in the 11th FYP period	Target in the 12th FYP period
Nationwide	20	16
Beijing	20	17
Tianjin	20	18
Hebei	20	17
Shanxi	22	16
Inner Mongol	22	15
Liaoning	20	17
Jilin	22	16
Heilongjiang	20	16
Shanghai	20	18
Jiangsu	20	18
Zhejiang	20	18

(continued)

Table 2.2 (continued)

Regions	Reduction of energy intensity (%)	
	Target in the 11th FYP period	Target in the 12th FYP period
Anhui	20	16
Fujian	16	16
Jiangxi	20	16
Shandong	22	17
Henan	20	16
Hubei	20	16
Hunan	20	16
Guangdong	16	18
Guangxi	15	15
Hainan	12	10
Chongqing	20	16
Sichuan	20	16
Guizhou	20	15
Yunan	17	15
Tibet	12	10
Shanxi	20	16
Gansu	20	15
Qinghai	17	10
Ningxia	20	15
Xinjiang	Further evaluation	10

Source Comprehensive work plan for energy conservation and emission reduction during the 12th five-year plan period (2011)

For promoting green and low-carbon development, Chinese government provided great financial support for energy saving and emission reduction. According to the estimation in the China Energy Efficiency Financing and Investment Report, a total of RMB 850 billion was invested directly to improve energy efficiency during the 11th FYP Period, taking up 0.92 % of the investment in fixed assets in the same period, which is equivalent to save as 0.34 billion tce and it takes 53.8 % of the energy-saving target. It is expected that the energy efficiency investment is hopeful to be RMB 1,525 billion during the 12th FYP Period (2013).

2.2.1.2 Promoting High-Quality Energy to Optimize Energy Mix

Coal-dominated energy structure is the fundamental cause of China's high energy carbonation and is also responsible for environmental pollution and GHG emissions. In recent years, a series of measures have been taken to optimize the energy mix and promote low-carbon energy development. The Action Plan for Air Pollution Prevention and Control, released by the Chinese Government in 2013, is aimed at decreasing to 65 % or less share of coal in primary energy consumption and a negative growth of coal consumption in the Beijing-Tianjin-Hebei (BTH) region, Yangtze River Delta (YRD) and Pearl River Delta (PRD) by 2017. The Energy Development Strategy Action Plan (2014–2020), released in 2014, requires that the total coal consumption should be controlled within 4.2 billion tons by 2020. The Interim Measures on Coal Consumption Reduction and Coal Alternatives in Key Areas, jointly issued by National Development and Reform Commission, Ministry of Industry and other four ministries in January 2015, clearly puts forward targets for Beijing, Tianjin, Hebei and Shandong. In other word, by 2017, the coal consumption shall be reduced by 13 million tons, 10 million tons, 40 million tons and 20 million tons in these four regions, respectively; and by 83 million tons cumulatively compared with 2012. In addition, the Chinese Government set the medium- and long-term objectives for non-fossil energy development: a share of 11.4 % in primary energy consumption by 2015 and 15 % by 2020. According to the China-US Joint Announcement on Climate Change and Clean Energy Cooperation in November 2014, China aims at increasing the share of non-fossil energy in primary energy consumption to about 20 % by 2030 (2014b).

2.2.1.3 Setting Targets for Reducing Carbon Emissions to Promote Low Carbon and Green Growth

Although China is a developing country, it still undertakes international responsibility. On June 2015, China released the Enhanced Actions on Climate Change: China's Intended Nationally Determined Contributions, which determines its actions by 2030 to lower carbon dioxide emissions per unit of GDP by 60–65 % from the 2005 level (2015e). This target shows a greater improvement than the target of 40–45 % decrease of carbon dioxide emissions per unit of GDP which is promised before Copenhagen Climate Change Conference in 2009. Furthermore, China also announces that by 2030 it will increase the forest stock volume by 4.5 billion cubic meters compared to the 2005 levels. On the occasion of President Xi's State Visit to Washington, D.C. in September 2015, the two Presidents reaffirm their determination to promote sustainable development and the transition to green, low-carbon, and climate-resilient economies. China plans to start in 2017 its national emission trading system, and commits to promote low-carbon buildings and transportation, with the share of green buildings reaching 50 % in newly built buildings in cities and towns by 2020 and the share of public transport in motorized travel reaching 30 % in big- and medium-sized cities by 2020. It will finalize next-stage fuel efficiency standards for heavy-duty vehicles in 2016 and implement them in 2019. Actions on HFCs continue to be supported and accelerated (2015f). China will actively undertake international responsibilities and obligations, actively involved in responding to global climate change negotiations, to actively participate in 2030 sustainable development agenda, according to the bulletin of the fifth plenary session of the 18th CPC Central Committee. China aims to realize green growth and sustainable development, and restricts energy consumption and energy intensity during the 13th FYP.

2.2.1.4 Implementing the "Four Revolutions and Cooperation" Strategy to Support Low-Carbon Energy

The "Four Revolutions and Cooperation" energy strategy, referred to energy consumption revolution, energy supply revolution, energy technology revolution, energy system revolution and all-round international cooperation, were raised by Chinese President Xi Jinping at the sixth meeting of the Central Financial Work Leading Group in June 2014. To meet the requirements of this strategy, China has launched a series of measures to promote the low-carbon transition, involving the control of energy and coal consumption and increase of the proportion of non-fossil energy. On the aspect of energy production and consumption, the Energy Development Strategy Action Plan (2014–2020) was issued by the State Council in November 2014. It is clearly stated that China will control the total primary energy consumption around 4.8 billion tce by 2020, of which natural gas should take up more than 10 % and coal less than 62 %. On the aspect of energy technology, a series of policy measures in favor of advanced technologies were introduced. For example, on February 16, 2015, Ministry of Science and Technology issued the Implementation Plan for the National Key Research and Development Project of New Energy Vehicles (Draft) in order to promote electric vehicles. On the aspect of energy system, the said Action Plan requires efforts to improve the market system, promote price reform, deepen reforms in key fields and key links, and perfect laws and regulations. In terms of international cooperation, Chinese President Xi Jinping proposed the strategic vision of Silk Road Economic Belt and the 21st Century Maritime Silk Road, collectively referred to as the "Belt and Road", in September and October 2013 respectively (2015g). The International Energy Transformation Forum called all participating organizations for strengthen cooperation in the areas of policy, technology and standards in the context of energy transition, and proposed to establish a global coalition of partner ries undertaking energy transition, and set up an "IRENA-China Research and Co-operation Centre for Energy Transition", which can support the activities of the proposed global coalition.

As indicated by these targets, China will take effective measures in the future to curtail high-carbon energy and expand the application of low-carbon energy, such as natural gas and non-fossil fuels, which provides a strong policy support for a green low-carbon transition in the energy sector.

2.2.2 Achievements

2.2.2.1 Stable and Rapid Economic Development

During the late 10th FYP period, China's energy consumption expanded at an ultra-high speed which even exceed the development speed of the national economy. In 2005, the energy elasticity coefficient hit 1.56. Owning to strong low-carbon development policy, the trend was reserved during the late five years, and the energy elasticity coefficient reduced to 0.58 in 2010. Policies and measures have been upgraded during the 12th FYP period. From 2011 to 2014, the energy consumption per unit of GDP was reduced by 13.4 %, which was equivalent to cumulative energy savings of 540 million tce. The economic dependence on energy has also been mitigated. In addition, China achieved an annual economic growth of 8.0 % during the four years based on an annual 4.3 % growth of energy consumption. Accordingly, the energy elasticity coefficient dropped to 0.36 in 2014.

2.2.2.2 Economic Restructuring and Economic Quality and Efficiency

China's low-carbon development policies, especially the stringent energy conservation policy, have successfully curbed the blind development of energy-intensive industries and played a positive role in the adjustment of overall industrial restructure and of the tertiary industries. In 2013, the tertiary industries overweight, for the first time, the secondary industries in the national economy. From 2010 to 2014, the proportion of the tertiary industries increased by 5.0 percentage points, while that of the primary and secondary industries dropped by 0.9 and 4.1 percentage points respectively. The contribution of the service industry to economic growth is also of significance.

2.2.2.3 Technological Progress and Industrial Upgrading

Industrial energy efficiency has improved steadily during the 12th FYP period. In 2012, coal consumption of thermal power generation decreased by 12.2 %, comparable energy consumption per ton of steel by 7.9 %, alternating current (AC) power consumption per ton of aluminum by 5 %, and energy consumption per ton of cement by 23.6 % over those in 2005. China has entered the international advanced ranks in terms of AC power consumption per ton of aluminum and coal consumption of coal-fired power supply. From 2011 onwards, a total of 218 technologies have been prioritized for promotion through six National Promotion Catalogues of National Key Energy-saving Technologies. The market share of a dozen of technologies, including turbine modernization technology, dry TRT technology for large blast furnace, energy control technology for the steel industry, and energy-saving ammonia synthesis technology, increased from the initial 5 % to over 70 % in 2014. As a result, the technological application has brought significant energy efficiency benefits to enterprises.

2.2.2.4 Energy Intensity and Carbon Intensity

Energy intensity and carbon intensity were dramatically cut down (Fig. 2.4) with the implementation of a series of policy measures, covering industrial restructuring, key projects, technological progress, policy incentives, supervision and

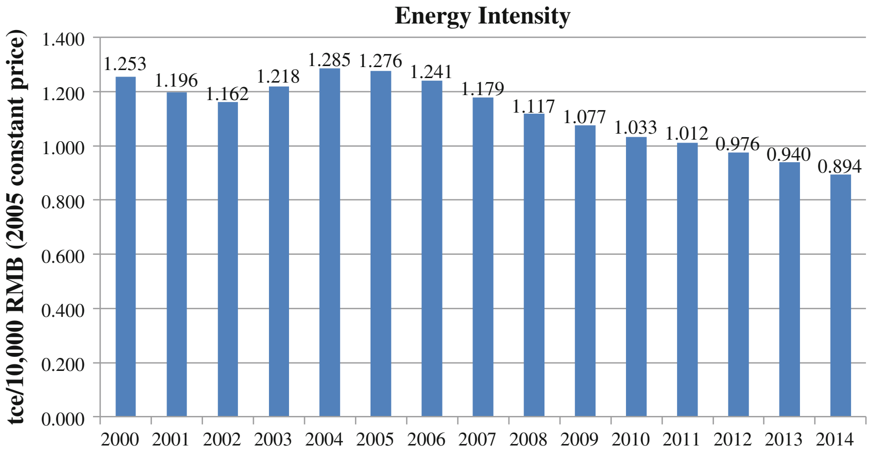

Fig. 2.4 Energy intensity (2000–2014). *Source* NBS (2015)

management, and public participation. It is estimated that energy intensity reduced by 19.1 % during the 11th FYP period (2005–2010) and by 13.3 % during the late four years (2010–2014). The latter reduction is equivalent to 82 % of the target set by the 12th FYP. Compared with 2005, the energy intensity dropped by about 30 % in 2014. Correspondingly, the CO_2 emissions per unit of GDP continue to decrease. So far, the Chinese government has issued national greenhouse gas emissions inventory in 1994, 2005 and 2008. The greenhouse gas emission total quantity for the three years are 3.650, 7.467 and 8.810 billion tons CO_2 eq, respectively; the carbon intensity for the three years are 0.524, 0.402 and 0.336 ton/thousand Yuan (at 2005 constant price).

2.2.2.5 Positive Progress in Air Pollution Control

China's air pollution control has been made positive progress owing to a series of measurements, for example, eliminating heavy energy-consuming enterprises, improving energy utilization ratio, developing renewable energy and controlling the total amount of coal consumption. The data from Ministry of Environmental Protection shows that the PM2.5 concentration value in BTH region and its around areas fell about 14.6 % in 2014. In the first half year of 2015, the mean ratio of days which reach the standard in BTH, YRD and PRD and 74 key cities was 68.0 %, 6.9 % increase as compared to the previous year. Specially, the PM2.5 mean concentration values fell 15.4 % in Beijing and its around areas, 22.1 % in BTH (with value of 78 mg/m^3), 16.2 % in YRD, 20.5 % in PRD, and 17.1 % in the 74 key cities, respectively. In addition, the mean concentration of PM10, SO_2 and NO_2 presented decrease tendency at the same time. These results demonstrated obvious progress in air pollution control.

2.3 Energy Demand Perspective Beyond to 2050

Actually, China's economic development is still in a low level, though it has become the world's second largest economy. In 2014, the per capita GDP was less than 1/4 of developed countries; and vehicles per 1,000 people, less than 1/5 of developed countries and 3/5 of the world average. China's urbanization rate stayed below 55 %, nearly ten percentage points lower than that of developed countries. Moreover, the economic development is uneven. The per capita GDP in the western region was less than half of that of the southeast coastal areas, and the per capita disposable income of rural residents, only 2/5 of urban residents. According to World Bank standards, more than 100 million people in China still live under the poverty line. In the foreseeable future, economic growth remains to be the chief task. Hence, significant increase of energy intensity and carbon intensity can be predictable under the current development model. A low-carbon pathway of development differentiated from the traditional industrialization becomes a daunting challenge for China and will be widely concerned (ERI 2015).

2.3.1 Methodology

Scenario analysis,[3] combined with the top–down approach and bottom–up approach, was adopted to make a comprehensive, systematic and quantitative study on the medium- and long-term energy development.

First, the energy use for building a moderately prosperous society by 2020 and reaching the level of moderately developed countries by 2050 is interpreted at a macro level, and economic and social situations are envisaged under the premise of achieving the goals. On the basis of full consideration of effects of internal and external conditions on energy use in the next 30–50 years, different energy and emission scenarios are built. Herein, appropriate modeling tools and end-use analysis are combined to quantitative estimate the energy use and carbon emissions, and then the possible emission path may be hackled and found (Fig. 2.5).

[3]Scenario analysis is a process of analyzing the feasibility and necessary conditions for achieving alternative possible outcomes. It does not forecast or show one exact picture of the future. Instead, scenario analysis examines the possible changes and their preconditions. It is designed to allow improved decision-making by allowing consideration of outcomes and their implications.

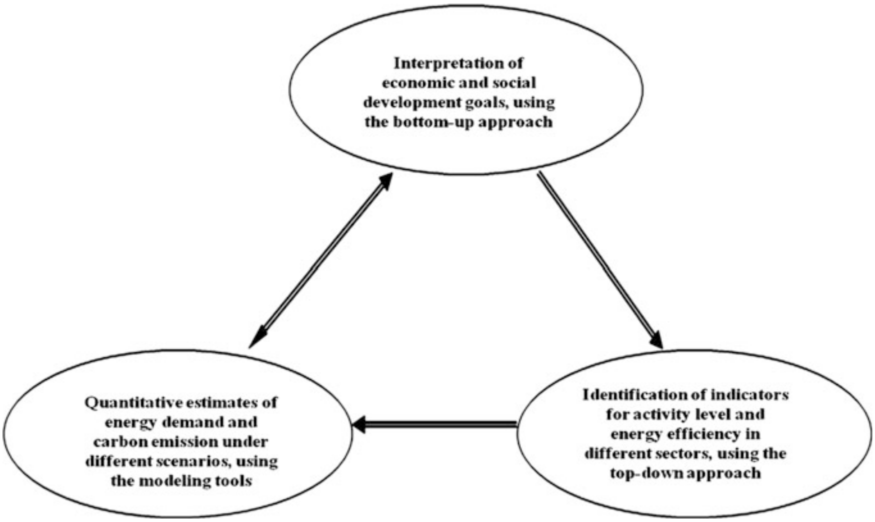

Fig. 2.5 Schematic map of research methodology

2.3.2 Scenario Design

In this study, the reference scenario (RS) and low carbon scenario (LCS) of low-carbon development towards 2050 were designed considering the research needs as well as previous study experiences by Energy Research Institute. The detailed illustrations of these two scenarios are presented as follows:

RS: describing energy use and carbon emissions for building a moderately developed country by 2050 in the context of national realities and trends. The scenario draws reference to the major developed countries, and takes into account the continuation of existing policies and potential technological advances under natural conditions, but neglects possible revolutionary technological breakthroughs and major policy changes.

LCS: describing energy use and carbon emissions given strengthened efforts in technological and economic, energy and emission aspects while meeting the requirements of sustainable development, energy security, domestic environment and low-carbon path. The scenario assumes significant improvement or revolutionary change in economic development patterns, energy mix, energy and emission technologies, and even lifestyles. Under this scenario, economic and social development is in harmony with energy and the environment. Therefore, LCS is also named the re-inventing Fire scenario.

Key assumptions about the two scenarios are described in Table 2.3.

Table 2.3 Key assumptions about the RS and LCS scenarios in 2050

	RS	LCS
GDP	Achieving the targets of the "three-step" strategy GDP annual growth: 2015–2020: 7 % 2020–2030: 5.5 % 2030–2050: 3 %	Basically the same as RS
Population	Peaking at 1.46 billion around 2030 and decreasing to 1.4 billion in 2050	Same as RS
Per capita GDP	USD 34,000 in 2050 (at 2010 constant prices)	Similar to RS
Industrial structure	Preliminary economic structure optimization: the tertiary industries rising to a major component in 2030 and heavy industry dominating the secondary industries	Further optimized economic structure similar to that of developed countries; rapid development of the emerging industries and the tertiary industries and secured important position of the information industry
Urbanization rate	60 % in 2020, 68 % in 2030, and 78 % in 2050	Similar to RS
Import and export pattern	From 2030 onwards, proportion of primary product exports drastically reduced and energy-intensive products to meet domestic demand	From 2030 onwards, proportion of primary product exports drastically reduced and energy-intensive products to meet domestic demand; experts of high value-added industries and services increased significantly
Environmental problems	Proper governance, but still treatment after pollution, reflecting the environmental Kuznets curve	Proper governance, Kuznets curve peaks and troughs narrowed and curve shape change from "∩" to "⌒"
Energy use technological advances	From 2040 onwards, wide application of advanced energy technologies; China to become the world's technology leader, with technical efficiency increased by 40 % compared with the current level	From 2030 onwards, wide application of advanced energy technologies. China to become a world leader in industries and other energy technologies, and in manufacturing energy-saving technologies with technical efficiency increased by 50 % compared with the current level
Solar and wind power generation technologies	Solar power cost of RMB 0.39/kWh in 2050; high penetration of onshore wind farms	Solar power cost of RMB 0.7/kWh in 2050; high penetration of onshore wind farms large-scale construction of offshore wind farms

(continued)

Table 2.3 (continued)

	RS	LCS
Nuclear power generation technology	Installed capacity of 53.15 million kW in 2020 and 350 million kW in 2050; rapid growth of nuclear power and large-scale construction of G4 nuclear power plants after 2030 to meet the fast-growing end demand	Installed capacity of 52 million kW in 2020 and 220 million kW in 2050; sustainable development of nuclear power with falling cost of renewable energy and revolutionary change in end demand
Coal technology	Supercritical and ultra-supercritical technology	Supercritical and ultra-supercritical technology before 2030 and IGCC after
Hydropower use	Installed capacity of about 500 million kW in 2050	Installed capacity of about 500 million kW in 2050
Peak steel production	Peaking at 850 million tons in 2020	Peaking at 680 million tons in 2020
Lifestyle	Full use of clean energy, high penetration of energy-efficient household appliances, commercial energy utilization in rural areas	Low-carbon, widely application of eco-friendly housing
Transport development	Rapid development, convenient travel by bus, perfect rail transit in large cities	Rapid development, perfect public transport network, green travel and perfect rail transit, full use of the Internet of Things (IoT) since 2020
Transport technology	Fuel economy: 20–40 %	Fuel economy: 30–60 %
Proportion of electric vehicles in private cars	Around 30 %	Around 80 %

Note Electric vehicles include plug-in hybrid electric vehicles. *Source* ERI (2009)

2.3.3 Conclusions

1. For achieving the set goals of economic and social development, China's total energy use and carbon emissions possibly continue to grow (Fig. 2.6). The building and transport sectors will be the major roles to lead the contribution, while the industrial sector will show slow growth after 2020. Unless breakthroughs in carbon capture and storage, the coal-dominated power structure will remain and the improvement of electrification will make it difficult to drastically cut carbon emissions.
2. In the absence of enhanced policy for energy conservation and emission reduction, China's energy use will reach the peak value of 8.84 billion tce[4]

[4]Primary energy is accounted on the electric equivalent basis, namely 1 kWh = 860 calories, sic passim excepting specially emphasis.

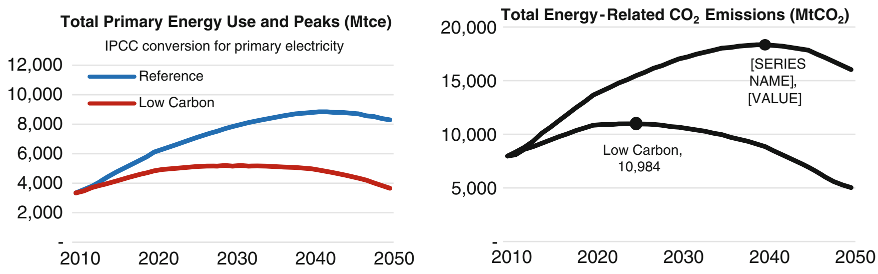

Fig. 2.6 China's energy use and carbon emissions trends. *Source* ERI (2009)

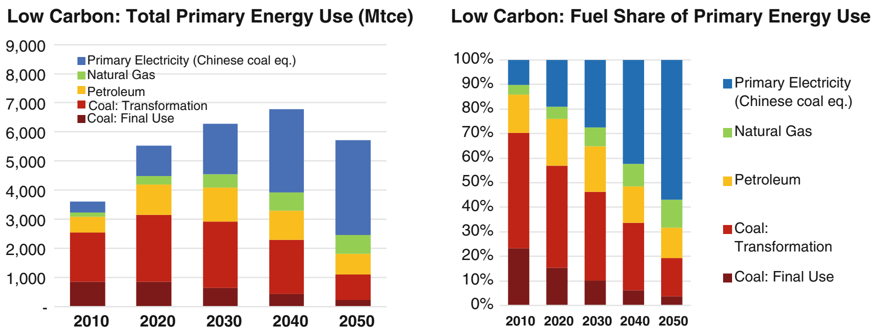

Fig. 2.7 China's energy consumption and its composition (LCS). *Source* ERI (2015)

around 2042 and attain 8.29 billion tce in 2050; and the CO_2 emissions will reach the peak of about 18.32 billion tons in 2042. Obviously, such high energy use and carbon emissions will undoubtedly pose serious challenges to China's sustainable development and the global energy market, investment, environmental protection and energy security.

3. Targeted measures, technology transfer and financial assistance from the international community may dramatically change the picture. Under the LCS, China's total energy use will reach its peak of 5.21 billion tce around 2032 and fall to 3.66 billion tce in 2050. The peak of total CO_2 emissions will arrive to 11 billion tons-carbon around 2027. In 2050, China reduce the total CO_2 emissions to 5.03 billion tons-carbon, 36.7 % lower than that in 2010, expecting to make a significant contribution to addressing global climate change.
4. Under the LCS, by 2050, more than half (57 %) of energy supply[5] in China will be from non-fossil energy, mainly renewable energy (Fig. 2.7). Non-fossil fuels

[5]Here, the primary energy is based on the coal equivalent calculation method, namely the coefficient for conversion of electric power into SCE (standard coal equivalent) is calculated on the basis of the data on average coal consumption in generating electric power.

will take up 19 % of the primary energy in 2020 and 27 % in 2030, fulfilling the anticipated international commitments.

5. China will experience three stages in economic and social development, featuring the continuous growth of energy use and carbon emissions (currently–2020), diversified development of energy (2021–2035) and remarkable CO_2 emission reduction (2036–2050), respectively. The second stage is critical to optimization of energy mix and obvious elimination of reliance on coal. It determines the arrival of the peak for fossil fuels use and economic development "decoupled" with CO_2 emissions. It is in this stage that China will strive to create a new pattern with balanced fossil and non-fossil energy development in 2050 to replace the current coal-based energy structure.
6. With the progress in economic restructuring and transformation, heavy energy-consuming products will reach the peak in succession, which reduce the demand for coal. Under the LCS, China's coal demand will reach its peak of 4 billion tons around 2020 and fall to 1.54 billion tons in 2050 under the contribution of high-speed development of wind energy, solar energy, hydropower, nuclear power and natural gas as well as high efficient utilization of coal. Since the coal demand will be mainly utilized by power sectors, the high efficient utilization of coal-fired boiler should be promoted continually.
7. Alternative advanced technologies and major technological breakthroughs are important prerequisite for low-carbon development. Science and technology guides economic and social development while affecting lifestyles, consumer behavior and values. The contribution of technological advances (including end-users and energy industries) to GHG emission reductions remains above 38 % over years and is expected to reach 50 % in 2050, according to studies. Therefore, a world-class equipment system for energy-intensive industries (including power plants) based on technological progress is vital to China's low-carbon transition.
8. Industrial, building, and transport sections are given equal priority in the effort to reduce CO_2 emissions, instead of the industrial sector solely. At present, the industrial sector is responsible for about 70 % of the total energy use and CO_2 emissions. According to the scenario analysis, with the gradual completion of industrialization and development of a circular economy, the metallurgy and building materials industries will be able to achieve emissions reduction as well as output value increase. Owing to multi-level structural adjustment and development of the energy saving potential in industrial sector itself, the growth of energy use and emissions will obviously slow down. Its contribution to national emissions will fall from 67 % in 2010 down to 53 % in 2050. Meanwhile, the commercial and residential, and transport sectors will see fast expansion of emissions as household consumption is focused on housing and travel. Under the LCS, in 2050, the contribution of the transport sector to national emissions will rise to 27 % from 9 % in 2010. The commercial and residential sectors will take power as the primary energy, mainly sourced from renewable energy generation, and reduce the share by emissions to 20 % in 2050 from 24 % in 2010 (Fig. 2.8).

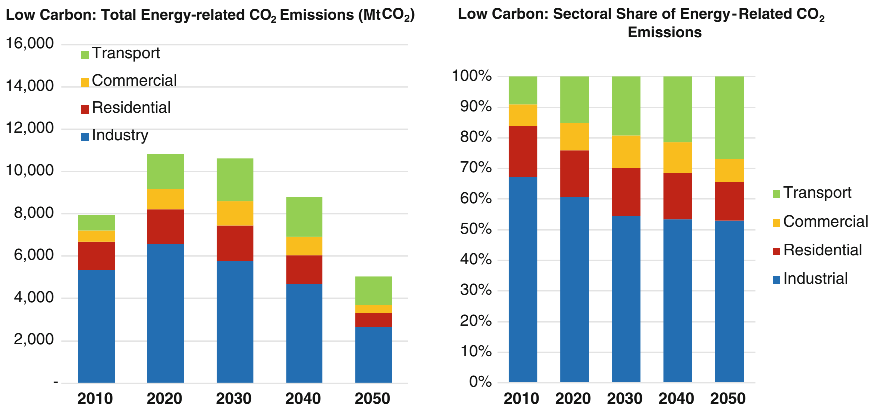

Fig. 2.8 China's energy use by sectors (LCS). *Source* ERI (2015)

9. Under the LCS, with the implementation of technology feasible, economic reasonable and social acceptable energy-saving measures, an addition of RMB 46 trillion (at 2010 constant prices) investment will be needed and the net income of RMB 22 trillion (at 2010 constant prices) will be obtained during 2010–2050. And it will increase earnings by reducing energy costs and using low-cost renewable energy power. Except for economic benefit, environmental and social benefits are also acquired with source pollution control. It is estimated that environmental loss is taken up 5–6 % in GDP, which equals to RMB 2.35 trillion to 2.82 trillion. In 2010, the loss of human health caused by air pollution and workers' health in the mining area was around RMB 305.1 billion. Compared with RS, the loss of environment and human health shows significantly decrease under the LCS, performs excellent environmental and social benefits.
10. China's low-carbon development faces many uncertainties, for example, apprehension of changes, technological innovation and technology transfer, and funding. A favorable external environment is also important. In fact, China is frequently misunderstood and even demonized in the use of international high-quality energy, introduction of advanced technologies, and development of hydropower and nuclear power. These negative factors, if not properly handled, will hinder the low-carbon transition of energy in China.

2.4 Road Map for Low-Carbon Transition and Green Development in Future

In the current trend, the total energy use in China will exceed 8 billion tce in 2050. Obviously, this situation will pose serious challenges to energy supply and the environment, as well as global response to climate change. China must adhere to energy mix adjustment, and endeavor to accomplish high-efficient, clean, green and low-carbon energy production and consumption.

2.4.1 Pathway I—Total Coal Consumption Peaking Around 2020

The low-carbon transition of coal-based energy structure first depends on the early arrival of peak values of the total coal consumption through strict control. Currently, more than 30 % of the Chinese urban population lives in air quality non-attainment areas. YRD, PRD and BTH still suffer serious acid rain, largely attributed to the coal-dominated energy structure. To achieve a green low-carbon transition, it is imperative to reduce coal use. The ongoing coal reduction initiative in major areas has produced initial results and the peak of coal use is around the corner. According to the study, by implementing a series of effective measures to reduce the end use while optimizing the generation mix and improving coal-fired power efficiency, the coal consumption could reach the peak around 2020.

2.4.2 Pathway II—CO_2 Emissions Peaking During 2025–2030

China is confronted with enormous pressure in the international climate negotiations amid increasing attention to global warming. To achieve low-carbon transition, China needs to approach the peak value of CO_2 emissions as soon as possible. Although China's cumulative emissions per capita in the industrialization process are still far below the level of developed countries, but its total emission has overtaken the United States, becoming the world's largest emitter. Additionally emissions per capita surpass the world average level and the annual national emissions account for over 25 % of the world total. According to the aforementioned study, with a great improvement in energy efficiency and substantial increase in renewable energy supply, China is expected to achieve the peak value in GHG emissions during 2025–2030.

2.4.3 Pathway III—Total Energy Use Peaking Around 2035

The control of total energy consumption is the key in the low-carbon transition. If appropriate measures are in place, the industrial sector will arrive energy use peak soon while pushing ahead the industrial revolution. The commercial and residential sectors can mitigate the lock-in effect of high energy consumption growth by promoting ultra-low power buildings, while the transport sector can minimizes oil consumption through “model innovation” and “technical changes”. Moreover, the next-generation grid in the processing and conversion sectors, which integrates resources at the supply side and demand side, is expected to increase the renewable energy penetration in the power sector. In this way, the total energy use can peak in 2035.

2.5 Policy Implications

2.5.1 Reshaping the Energy Strategy in the Interest of Green, Low-Carbon Transition

Under the LCS, China is likely to achieve a 6-fold economic growth with only a 9 % increase of primary energy use over 2010 given energy services available. By then, 57 % of energy supply will come from non-fossil energy sources, CO_2 emissions peak early, and emissions of major pollutants substantially decrease. To realize these objectives, China should reshape the energy strategy that injects a new impetus to efficient, green, low-carbon development by changing the traditional development ideas, production and use patterns, and technical and institutional systems. The coal consumption will go down gradually with the development of energy structure transformation. But coal and coal power will still be the main energy and power sources in recent and middle period. Hence, to achieve clean and high efficient utilization of coal is China’s realistic choice. It is needed to strengthen coal washing, generalize clean and high efficient boilers, develop clean combustion and promote carbon capture and storage, etc.

2.5.2 Incorporating the Low-Carbon Concept into Industrialization, Urbanization, Internationalization and Market-Oriented Development

Low-carbon industrialization should be armed with a new philosophy that emphasizes the upgrading of traditional industries, expansion of high-tech industries and development of producer services. In the development of automobile and housing markets, reasonable regulation should be provided to guide residential consumption. It is recommended to focus on four aspects: regulation of consumption growth, advanced and efficient technologies and services, efficiency of end-use equipment, and low-carbon energy industry. China should also foster low-carbon ways of production and life as early as possible before 2020 and rationalize the planning for cities with different sizes and internal functional areas, to minimize energy waste derived from urban planning.

2.5.3 *Meeting the New Age of Low Carbon: Electrified Energy System*

Per capita energy use and per capita power use are two major measures of modernization level of a country. Compared with the Industrial Revolution II, the new age witnesses broad and dispersed power demand, and shifts to distributed power supply and in-depth grid integration with the Internet, intellectualization and IoT. Under the LCS, during 2010–2050, the electrification rate will increase from 18 to 41 % and the proportion of non-fossil power supply from 24 to 94 %. The innovation in concept, technology and institution is imperative, so as to promote the clean, low-carbon, interconnected, sustainable development of the power system. On the demand side, the penetration of power in end users should be substantially increased to realize coal-free buildings and oil-free transport. On the supply side, renewable energy should be used to provide clean carbon-free electricity at nearly zero marginal cost; in addition, the power supply pattern, by setting the renewable energy and nuclear power to be the major power supply sources, and efficient fossil power to be the supplement, would be considered to provide flexibility services in the development of non-fossil power.

2.5.4 *Speeding up the Institutional Reform to Release Reform and Ecological Bonus*

Low-carbon energy development does not come true naturally. It is, in fact, an all-around reform with equal importance as the reform and opening up. It relates to all aspects of the whole society and involves fundamental change to the technical route and development path. The picture described under the LCS is underpinned by forceful reforms of governance and market mechanisms and driven by new industrial forms, technologies and business models. To this end, the government should make overall planning and lead energy mix optimization, to avoid local protectionism. Energy-related pricing mechanisms such as capital, labor, land, resources, and environmental elements, should be rationalized. A fair, competitive market environment that reflects supply and demand, scarcity and environmental externalities should be well established.

2.6 Deepening Regional Energy Cooperation

2.6.1 Visioning Regional Cooperation for Accelerating Low Carbon Green Economy

At present, green growth and sustainable development has become the consensus of the major countries, China need to change the concept of energy cooperation, and strengthen the cooperation of energy efficiency, renewable energy. First, escalating the regional energy transition process, realize the utilization of energy in water, wind, solar, and biomass adapting to local resource conditions. Make energy more accessible and affordable for everyone. Strengthen regional grid interconnection with Southeast Asia, South Asia, and Northeast Asia, improve the power grid for renewable energy consumptive capacity and promote renewable energy consumption. Second, focus on cooperation of energy efficiency and energy saving, strengthen cooperation in the field of clean coal utilization, actively participate in the construction of new coal-fired power plant projects in neighboring countries, and strengthen the cooperation in energy efficiency improvement in the areas of industry, building, and transportation. Third, strengthen energy technology cooperation with European. Establish a joint funding mechanism, while promoting the formation of the European developed countries to provide technical assistance to, share experience with, and enhance capacity building programs for the developing countries.

2.6.2 Creating a New Pattern of All-Round Cooperation—The Belt and Road Initiative

Take the Belt and Road initiative as an opportunity to deepen the international energy cooperation, to create a new pattern of all-round energy cooperation. First, promote the Belt and Road align with the initiatives proposed by countries along the Belt and Road. Based on the good cooperation with Mongolia and Russia, strengthen the alignment of Silk Road Economic Belt and Korea Eurasian initiative, 21st-Century Maritime Silk Road and Indian Monsoon Plan in the energy sector. In particular, China and India can strengthen cooperation in oil-rich areas, such as in Central Asia and Middle East. Thus progress Bangladesh-China-India-Myanmar Economic Corridor base on bilateral cooperation. Second, deepen the cooperation in the involved regional energy. Association of South-East Asian Nations (ASEAN), Northeast Asia and the Greater Tumen Area should be enhanced. For example, though the cooperation is handicapped by complex interwoven interests within ASEAN and the recent South China Sea issue, China should start with specific energy governance projects and then gradually expand to mechanisms constructions, considering ASEAN’s strong desire. Most countries in ASEAN are developing countries, considering the complementarity of energy cooperation between China and these countries are relatively strong, primary measures can be taken from the aspects of renewable energy development, energy technology cooperation, oil/gas trade platform establish, regional power grid construction and nuclear safety utilization. Meanwhile, strengthen the energy cooperation under ASEAN+3, based on the consensuses of the Sixth China-Korea-Japan Summit, strengthen trilateral cooperation on improvement of production capacity of energy infrastructure and electricity, strengthen cooperation on LNG to enhance the liquidity and efficiency of the LNG market in Northeast Asia, and advance ASEAN+3 energy cooperation with the trilateral cooperation serving as an engine.

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