Chapter 2
INDC and Low-Carbon Technology Deployment Scenarios: China

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Abstract Low-Carbon Technologies (LCTs) play an important role in achieving China's Intended Nationally Determined Contributions (INDC) targets. According to the result of our scenario analysis, if advanced energy-saving technology, renewable energy, and other measures are promoted and extensively applied, China's carbon emission will achieve its peaking at around 2027. With proper energy policies, China can overcome barriers and challenges for LCTs diffusion, achieving huge environmental and social benefits.

1 Introduction

Since entering the twenty-first century, along with the accelerating urbanization and industrialization in China, energy consumption increases rapidly. The consumption of primary energy in China has increased from 1.46 billion tons of coal equivalent (tce) in 2006 to 4.3 billion tce in 2015, with an average annual increase of 190 million tce/year and an average annual growth rate of 7.5% (China Statistics Bureau 2015, 2016). The majority consumption of energy in China is coal and oil. Despite the share of non-fossil energy consumption increases year by year, from 3% in 1980 to 12% in 2015, the rapid increase in fossil energy consumption results in an enormous growth of carbon dioxide (CO_2) emission. In 2015, the CO_2 emission in China was approximately 9.5 billion tons, constituting one quarter of world total emission, which equals to 7 tons per capita.

Since the 12th Five-Year Plan period (2010–2015), especially after 2012, China's economy enters a period of new normal. Energy consumption intensity declined steadily, renewable energy achieved leap-forward development, growth rate of CO_2 emissions dropped significantly, and low-carbon transition became

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emerging trend. From 2012 to 2015, the average annual increase in energy consumption is 90 million tce, while it is estimated that the carbon emission increases 200 million t/a, which means the average annual increase rate is 60% of that of the 11th Five-Year Plan period (2005–2010) (Fig. 1). The growth rate of coal consumption in China has been negative for two years, and the share of coal consumption in primary energy decreased steadily. Meanwhile, the share of the renewable energy in primary energy has increased consistently (Fig. 2).

Since 2006, Chinese government attaches great importance to the work of energy conservation and emission reduction, putting forward obligatory targets in succession, such as 20% reduction in energy intensity of GDP during the 11th Five-Year Plan period; 16% reduction in energy intensity of GDP during the 12th Five-Year Plan period; 15% reduction in energy intensity of GDP; 18% reduction in CO_2 emission intensity of GDP, and upper limit of energy consumption controlled at 4.8 billion tce during the 13th Five-Year Plan period (2016–2020). The Chinese government also makes the commitment to cut off the CO_2 emission intensity of GDP by 40–45% in 2020 compared to 2005. According to the data from The World Bank (2016), in recent two decades, China's accumulative energy conservation amount exceeds half of world total, up to 52%.

Before the Paris climate conference in 2015 (United Nations Framework Convention on Climate Change 2015), China proposed positively Intended Nationally Determined Contributions (INDC) targets, including 60–65% reduction CO_2 emission intensity of GDP in 2030 from the 2005 level, non-fossil fuels share in primary energy consumption growing up to around 20% in 2030, carbon emission reaching the peak around 2030 and making best efforts to peak early,

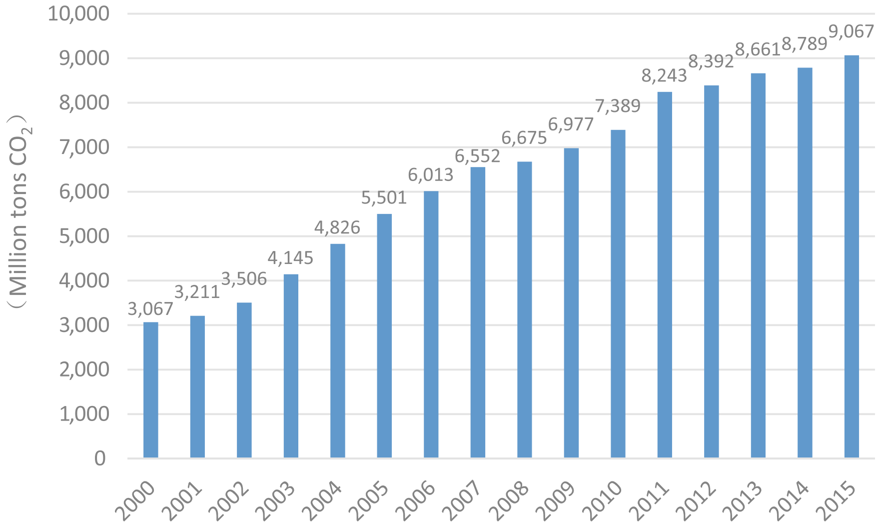

Fig. 1 Energy-related carbon emission 2000–2015. *Source* Energy consumption data come from NBS (2016) and emission factor is IPCC default (2016)

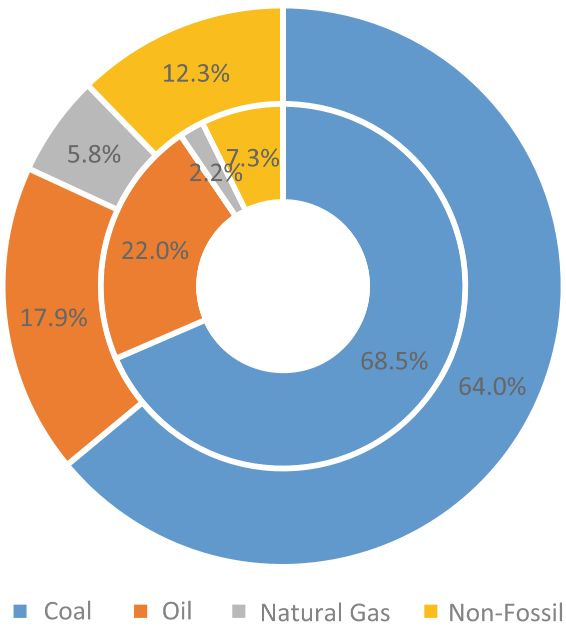

Fig. 2 Comparison of primary energy consumption mix between 2000 (*inner circle*) and 2015 (*outer circle*). *Source* NBS, 2016

forest stock volume increasing 4.5 billion m^3 in 2030 on the 2005 level (Department of Climate Change, National Development and Reform Commission of China 2015). To achieve the target of 60–65% reduction CO_2 emission intensity of GDP in 2030 from the 2005 level, the annual rate of decline of China's CO_2 emissions intensity will accelerate from 3.3 to 3.9% in the 2005–2020 period to 4.0–4.4% in the 2020–2030 period.

In this chapter, two scenarios have been designed to make a comparative analysis on the energy demand and CO_2 emissions from different sectors in China. By analyzing the characteristics and economies of LCTs, authors give the pathway to realize China's INDC targets. Meanwhile, this chapter goes on to make a number of recommendations to improve the context of LCTs transfer between countries in the region.

2 INDC Targets

China's INDC clearly stated that the targets are aimed at CO_2 emission reduction. According to the overall conditions of China's greenhouse gas (GHG) emission, CO_2 emission accounts for over 70% of the total GHG emission; thus, the control of CO_2 emission guarantees that GHG emission is controlled. Meanwhile, the INDC targets proposed by China is an objective based on the carbon intensity, which consists of two elements: carbon emission and GDP. In other words, the target is to reduce CO_2 emission as well as to maintain rapid economic growth before 2030. Besides, the target of reaching CO_2 emission peak before 2030 requires China to change the development mode fundamentally. Setting the CO_2 emission peak means fossil energy consumption does not increase with economy growth, as well as continuously increasing energy demand. At that point, additional increase in energy demand must be fulfilled by non-fossil fuels, meaning that economic growth is totally decoupled from the increase in fossil energy consumption and CO_2 emission. After raising the CO_2 emission peak target, 11 provinces and cities including Beijing, Sichuan, Hainan, and Shenzhen founded “the Alliance of Peaking Pioneer Cities” and came up with a time schedule of achieving individual emission peak (Fig. 3).

The Fifth Plenary Session of the eighteenth Central Committee of the Communist Party of China put forward five development ideas of innovation, coordination, green, open, and sharing. Promoting low-carbon energy transformation is the trend of economic development and environment improvement. Making great efforts for the progress of low-carbon energy will not only cultivate new developing dynamic with characteristics of low-carbon, green, and clean, drive the economic structure upgrading and development mode transformation, and accelerate the renewable energy industry, but also greatly improve the ecological environment. This is no doubt a win–win approach.

Low-carbon development in China has its own characteristics. China’s economy will maintain a moderate to high growth speed for a certain period, as along with the improvement of people’s living standard. Thus, the total energy consumption

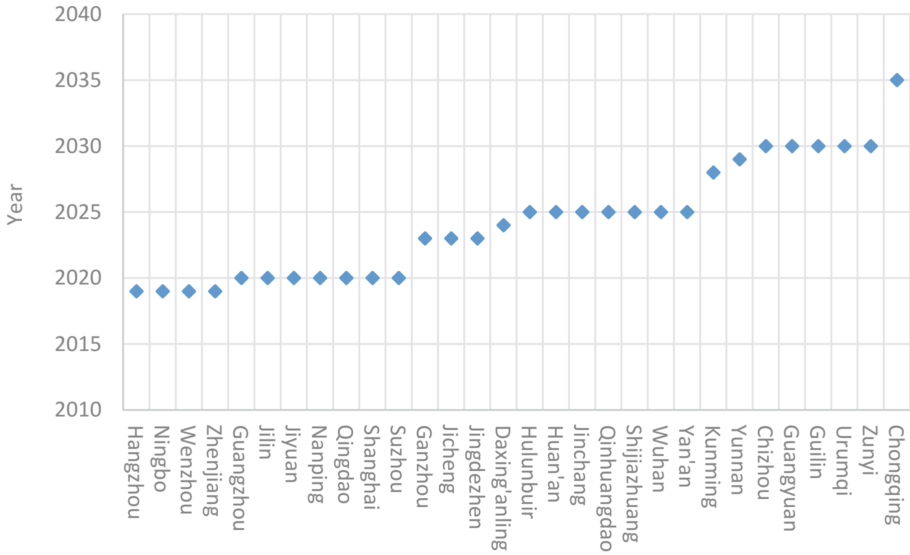

Fig. 3 Emission peaking timetable of selected cities in China. *Source* Collected from Cities’ Planning, 2016

will grow accordingly, making massive development and utilization of renewable energy an inevitable path for China's low-carbon development. Consequently, China claims to actively promote hydropower under the premise of proper ecological environment protection and immigrants' relocation, safely and efficiently promote nuclear power development, accelerate the development of wind power and the solar power, and encourage the progress of geothermal energy, biomass energy, and ocean energy. By 2020, installed capacity of wind power and solar photovoltaic (PV) will reach 200 million kW and 100 million kW, respectively, while geothermal energy utilization will reach 50 million tce.

Looking from the energy structure, currently, energy consumption from industrial sector accounts for approximately 70% of China's total energy consumption and CO_2 emission from industrial sector accounts for more than 60% of the total CO_2 emission. In the future, along with the economic restructuring in China, this proportion will decline to some extent. However, in the short term, energy consumed by industrial sector will still be the largest composition of China's energy consumption (Fig. 4), which means energy conservation and emission reduction in industrial sector are crucial to China's short-term low-carbon development. In future, energy consumption in commercial, residential, and transportation sectors will maintain rapid growth, and the proportion of CO_2 emission in these sectors will grow continuously. At the same time, commercial, residential, and transportation sectors will also indirectly stimulate the energy consumption and carbon emission of relative industrial sectors. Therefore, Low-Carbon Technologies (LCTs) development in commercial, residential, and transportation sectors is the key issue influencing the achievement of the China's carbon emission peak target.

3 Methodology

This study uses a combination of bottom-up and top-down analysis. We research mid-/long-term energy and carbon emission development systematically and analytically. Cost-effectiveness of LCTs, environmental and social impacts are also analysed.

The top-down analysis is based on macrolevel inputs of GDP, population, and urbanization (Table 1). We also add experiences and lessons from advanced countries, combined with China's conditions, development stages and levels, forecasting future economic development, activity levels, energy demand, and environmental status while helping to realize China's modernization development goals.

The bottom-up analysis is focused on the carbon emission sectors of China's economy: industry, buildings, transport, and transformation (including both electricity and other energy supply sectors). The analysis includes assessments of sectoral energy demand, activity levels, and structural change, provides technical and policy roadmaps, calculates cost-effectiveness, and discusses related environmental impacts under the two different scenarios.

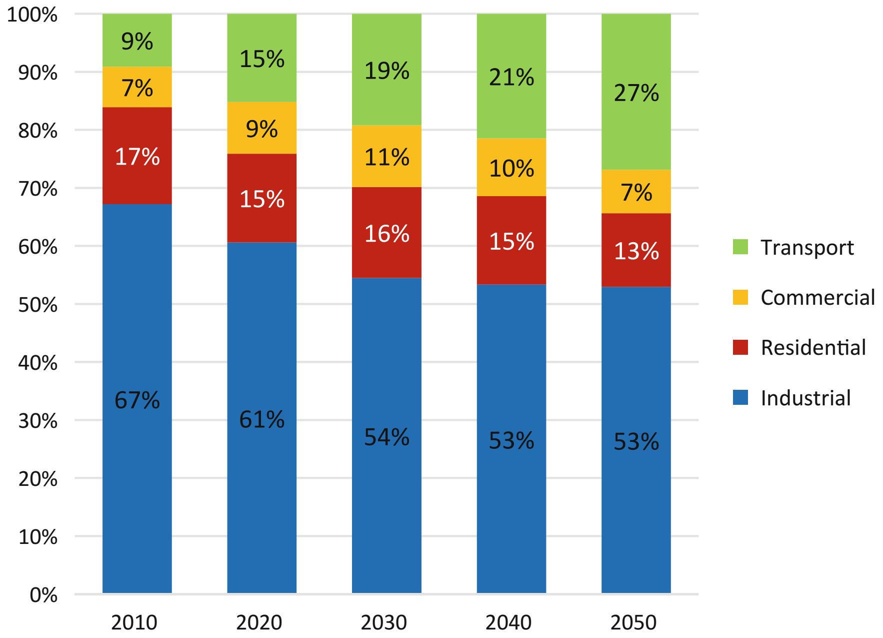

Fig. 4 Proportion of carbon emission from different sectors, 2010–2050. *Source* Authors

Table 1 Perspective for future China's social and economic development to 2050

	2015	2020	2030	2040	2050
Population (100 million)	13.8	14.2	14.4	14.2	13.7
Urbanization rate (%)	56	60	68	74	78
GDP growth rate (%)	6.5	6.0	5.2	3.6	2.6

Source Energy Research Institute, National Development and Reform Commission of China (2016)

3.1 Macroeconomic Assumptions

Three key macroeconomic assumptions were used in this analysis: population growth, urbanization rates, and GDP growth rates (Table 1). The projected population growth and urbanization rates up to 2050 are based on data from China's National Bureau of Statistics (NBS), and the projected GDP growth rates up to 2050 are based on data from NBS, and the China Macroeconomic information network. Each macroeconomic assumption was compared to international projections from the United Nations, the World Bank, the International Energy Agency (IEA), and the Organization for Economic Cooperation and Development (OECD). These key macroeconomic variables indicate four points as follows:

- Population: China's population will peak in 2030 at 1.44 billion, an increase of 93 million over 2010 levels, and then decline to 1.37 billion in 2050.
- Urbanization: In 2050, China's urbanization rate will be 78%, with 400 million more people living in cities than in 2010.
- GDP: According to the new normal, China's GDP will grow 6.5% from 2016 to 2020 and slow to 2.6% from 2046 to 2050.
- Overall: China's GDP will reach 245 trillion Yuan (US$40.87 trillion in 2010 US$), 6.9 times higher than the 2010 level. GDP per capita will be 179,390 Yuan (US$29,900 2010 US$), increasing 6.7 times compared to 2010.

3.2 *Definition of Scenarios*

To analyze the contribution of LCTs to CO_2 emission reduction, two scenario hypotheses were made in this study: the reference scenario and the LCTs scenario.

The reference scenario: Considering the situations as economic growth slowing down and industrial restructuring, the development of major sectors continues on the past mode, as mainly intended to meet the needs of domestic development and improve the people's livelihood. China set the short-term goals of cutting off the CO_2 emission intensity of GDP by 40–45%, raising up the share of non-fossil energy to 15% in 2020, and mid-term goals of cutting off the CO_2 emission intensity of GDP by 60–65%, raising up non-fossil energy share to 20% in 2030. Current policies and mainstream technologies were adopted continuously, but there are no additional policies and measures dealing with climate change. According to the data in "Energy development strategic action plan (2014–2020)" issued by the State Council in 2014, the upper limit of energy consumption is approximately 4.8 billion tce (3.36 billion toe) by 2020. The total consumption of primary energy and the energy mix in the reference scenario are shown in Table 2.

The LCTs scenario: Assuming the same macro-index of economy, population, urbanization rate as the reference scenario and strengthening policy support, energy-efficient and energy-saving technologies are widely used in coal-burning power generation, building materials, steel, chemicals, construction, transportation (electric vehicles), mining, and other sectors, and the development and utilization of renewable and new energies such as wind power, bioenergy, solar energy,

Table 2 Total primary energy consumption and energy mix (reference)

Year	2020	2030	2040	2050
Primary energy consumption (10^8toe)	33.6	36.8	39.3	41.8
Fossil energy consumption (10^8toe)	28.6	29.4	27.5	25.1
Share of coal and oil (%)	75	67	56	45
Share of natural gas (%)	10	13	14	15

Source Authors

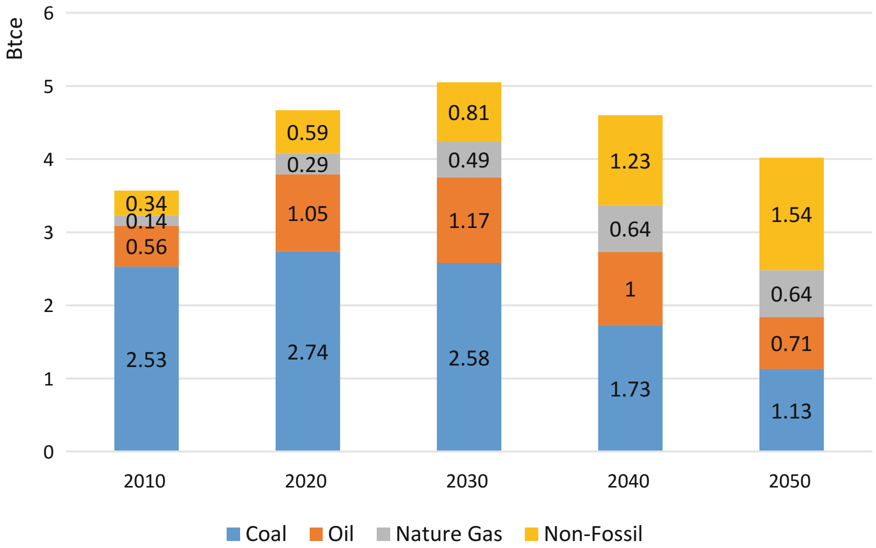

Fig. 5 Total primary energy demand and energy mix in the LCTs scenario, 2010–2050. *Source* Authors

hydropower, thermal power, and fuel cells are witnessed substantial progress. Meanwhile, technology integration and system innovation are realized, and the integrative development and utilization of energy with new technologies such as Internet, networking, and new materials are accelerated. Thus, a world leading new generation of energy technology system is created. The primary energy consumption and the proportion of fossil energy consumption in the LCTs scenario are shown in Fig. 5.

3.3 Sectoral Analysis

This analysis focuses on four key end-use energy-consuming sectors of China's economy: buildings, transportation, industry, and transformation (which includes electricity and energy supply). For each sector, extensive research and modeling was conducted to understand the most cost-effective, technologically feasible means for China to meet its overarching development goals, while also meeting individual sector goals. The sector-level visions that guided this analysis are that by 2050:

- Buildings and communities will be self-sustained and resilient with increased comfort levels.
- Industry will be world class in terms of energy efficiency and will have moved away from carbon-intensive fuels.

- Transportation systems will provide increased mobility, but more efficiently, with fewer emissions and lower costs.
- Transformation will provide the foundation for a dynamic economy and resilient nation, ensuring the health of the people and the restoration of the ecological environment with a resource supply mix, that is, secure, flexible, clean, and affordable.
- Technical improvement options are considered within each sector that efficiently and cost-effectively reduce demand and environmental impacts.

3.4 Modeling

Energy-related CO_2 emissions at the national, sector, and subsector levels were calculated using the primary energy results for all fossil fuels reported by the Long-range Energy Alternate Planning System (LEAP) model and China-specific CO_2 emissions factors for these fuels. The LEAP model provided the results for the total primary energy consumption of coal, natural gas, and crude oil and oil products. The primary energy consumption of each individual fuel is then multiplied by that fuel's CO_2 emissions factor to calculate its energy-related CO_2 emissions. For example, the energy-related CO_2 emissions from coal consumption are calculated as follows:

$$\text{Energy-CO}_2\text{ coal} = \text{PEC}_{\text{coal}} * \text{CO}_2\text{ EF}_{\text{coal}}$$

where

PEC_{coal} is the primary energy consumption of coal, in Mtce, and
$CO_2\ EF_{coal}$ is the China-specific CO_2 emissions factor for coal, in tCO_2 per tce.

The sum of CO_2 emissions from coal, natural gas, crude oil, and oil products is taken to be the total energy-related CO_2 emissions. The Energy Research Institute provided the China-specific CO_2 emissions factors used in this study, which are similar to the IPCC emission factors (Table 3).

Table 3 IPCC and China-specific emissions factors for coal, petroleum, and natural gas (tCO_2/tce)

	IPCC recommended emission factors	China-specific emission factors
Coal	2.79	2.72
Petroleum	2.15	2.17
Natural Gas	1.64	1.63

Source IPCC (2016)

3.5 Economical Analysis of Key LCTs

All improvement measures for each sector were evaluated for cost-effectiveness. We used net present value (NPV) calculations to analyze the additional investment costs and net economic benefits of the LCTs scenario compared to the reference scenario. This study evaluated the cost-effectiveness of the proposed technological options using life cycle and system analysis approaches to ensure the economic feasibility of the low-carbon development for each sector. For each specific technology, this study calculated the needed investment cost, possible additional operational and maintenance cost, and energy-saving benefits. Based on relevant research (Department of Climate Change, National Development and Reform Commission of China 2015), this study uses a 5% real social discount rate. In the cost estimation, this study did not take into account possible financing and management transaction costs when implementing the technological and policy solutions. When analyzing the cost-effectiveness, this study also did not take into account the health or environmental benefits of implementing the LCTs Scenario.

4 Low-Carbon Technologies

4.1 Clean Coal Power Generation Technologies

Taking into account China's energy demand and resource endowments, coal will still take the dominant position in China's energy structure within a period of time. China's coal consumption in 2020, 2030, and 2050 will be 2.74, 2.58, and 1.13 billion tce, respectively, in the LCTs scenario. Utilization of clean coal technology is an important subject for China's energy science and technology development before 2050. Since electric power is the main sector of China's coal consumption, extensive attention should be paid to advanced and efficient clean coal power generation technologies (Dai and Hu 2013).

Ultra-supercritical power generation

By far, the average power supply efficiency of coal-fired thermal power worldwide is 32%. Under this thermal efficiency, 1 kWh causes 1,200 g CO_2 emission. If using ultra-supercritical units with 45% power supply efficiency, 1 kWh causes 780 g CO_2 emission, which means by using the mature ultra-supercritical technology, the CO_2 emission can be reduced by 35%. Compared with ultra-supercritical technology at 600 °C, ultra-supercritical coal-fired thermal power generation technology at 700 °C will increase the power supply efficiency to 50%, further reducing 70 g coal consumption, leading to a 14% reduction in CO_2 emission. Currently, the investment is 1,800–2,200 Yuan/tCO_2.

Integrated gasification combined cycle (IGCC) generation system

The efficiency of IGCC is 40–43% currently and is expected to reach 50% in the future. When operating the system, 1 GJ heat supply will have 76 kg CO_2 emission reduction. Assuming each heating period needs 500,000 GJ heat supply, the average annual CO_2 emission reduction is 38,000 tCO_2, with the cost of 370–1,100 Yuan/tCO_2.

Carbon capture and store (CCS)

By far, the cost of CCS is 200–500 Yuan/tCO_2, and if enhanced oil production is used, the cost of CCS will be partly offset. By 2030, due to the improvement in CCS technique, the cost will be reduced to 150 Yuan/tCO_2.

4.2 Nuclear Power

From the perspective of the overall life cycle, nuclear power has higher cost than fossil energy power generation. The cost of the third-generation nuclear power generation is about 300–320 Yuan/MWh, which is about 30–120 Yuan/MWh higher than the cost of coal-fired thermal power plant or gas power plant.

4.3 Wind Power

During the recent decade, the cost of land wind power shows a significant downward trend, approaching to conventional energy in terms of cost. Cost of the large-scale land wind farm is around 6,000 Yuan/kW, while cost of offshore wind farm is 35–100% more. At present, the best land wind farm power cost is 0.2–0.25 Yuan/kWh.

4.4 Solar PV

In recent years, China has a great development in producing and in the application of PV modules. Thanks to the mass production, the cost of PV modules decreases rapidly. Considering the market price of household PV power plant construction, the total cost adds up to 10,000 Yuan/kW (Table 4).

Table 4 Key technologies of power generation

Name	Benefits	Investment	Potentials (to 2030) (TWh)
Ultra-supercritical power generation	420 $kgCO_2$/MWh	1,800–2,200 Yuan/tCO_2	700
Integrated gasification combined cycle (IGCC) generation system	76 kg CO_2/GJ	370–1,100 Yuan/tCO_2	377
Carbon capture and store (CCS)	Zero emission	200–500 Yuan/tCO_2	
Nuclear power	Zero emission	300–320 Yuan/MWh	624
Wind power	Zero emission	200–500 Yuan/MWh	1,163
Solar PV	Zero emission	500–800 Yuan/MWh	483

Source Dai and Bai (2015)

5 Energy-Efficient Technologies

5.1 Industrial Energy-Saving Technologies

China's industrial sector is the country's primary source of energy-related CO_2 emissions. There are four key ways to reduce carbon emission in transportation: structural shift to the service sector and higher-value-added industries; production demand reduction driven by longer-lasting buildings and infrastructure, improved material quality, increased recycling, and changes to the import/export structure; energy efficiency improvement; and fuel switches to lower CO_2 emission fuels and electrification following decarbonization of the electric grid (National Development and Reform Commission of China 2016a).

Though China's industrial energy efficiency has improved over the past decade, the energy intensity of China's major industrial subsectors lags behind the international levels (Energy Research Institute, National Development and Reform Commission of China 2009). According to estimation, high energy consumption product in China such as ordinary steel, cement, and ammonia have 50, 60, and 33% higher energy intensity, respectively, compared with those of the most advanced countries, leaving large improvement space. Industrial energy saving includes a wide range of technologies, but in general, cement, iron, and steel production sectors have largest potential of energy saving and emission reduction (Dai and Bai 2015). Tables 5 and 6 show the key LCTs of these two industries.

Table 5 Key technologies of energy saving in iron and steel production process

Name	Application condition	Benefits	Investment ($Yuan/tCO_2$)
Coke dry quenching (CDQ)	Coke oven with an annual production capacity over 30 t	74.8 $kgCO_2/t$ J	1,300–2,000
Coal moisture control (CMC)	Coking coal moisture greater than 9.5%	74.8 $kgCO_2/t$ J	1,500–2,200
Sintering waste heat recovery	Large and medium sintering machine	21.8 $kgCO_2/t$ Sinter ore	1,300–1,700
Combined cycle power plant (CCPP)	Annual output larger than 5 million tons, single machine no less than 15 MW	20.9 $kgCO_2/t$ Fe	1,100–1,500

Source Dai and Bai (2015)

Table 6 Key technologies of energy saving in cement production process

Name	Application condition	Benefits	Investment ($Yuan/tCO_2$)
Technology of pure low-temperature waste heat power generation in cement plant	Large and medium scale of NSP cement production lines	31.8 $kgCO_2/t$ cement	900–1,300
Multichannel burner technology	New dry cement production line, matching the kiln type fuel	3.0 $kgCO_2/t$ clinker	200–600
High solid–air ratio suspension preheating decomposition theory	Small and medium scale of NSP cement production lines	38.9 $kgCO_2/t$ clinker	900–1,500

Source Dai and Bai (2015)

5.2 Transportation Energy-Saving Technologies

The proportion of energy consumption from transportation sector is not high, but it is one of the fastest developing sectors and highly relied on oil and other liquid fuels. There are four key ways to reduce CO_2 emission in transportation: (i) activity reduction due to economic structural shift, improved layout of cities and industry, and advanced logistics; (ii) mode shifting from trucks, airplanes, and private autos to more-efficient rail, water, and high-speed rail; (iii) increasing vehicle efficiency using technology and design improvements; and (iv) fuel switching to electricity, natural gas, and biofuels.

Fuel vehicles will remain dominant of China's automotive vehicle market within a certain period. Improvement in fuel efficiency comes from innovations in different items, including engine, transmission device, light weight, gas dynamic performance, auxiliary system, and air-conditioning and tires, some of which are already become economically competitive. Among these technologies, conventional technologies in oil saving and improving fuel efficiency such as engine technology, transmission technology, and lightweight technology have higher degree of marketization.

In recent years, electric vehicles developed rapidly. By far, China has independently developed pure electric buses and cars and accomplished some demonstrative achievements such as pure electric bus technology and charging station construction. Under the encouragement of relevant policies, China's electric vehicles will achieve a significant development.

5.3 Energy-Saving Technologies in Commercial and Residential Sector

Energy-saving potential in commercial and residential sectors is mainly derived from building energy-saving technologies and utilization of new energy. There are five key ways to reduce carbon emission in building: (i) advanced construction practices including prefabricated buildings; (ii) reduced building energy demand through integrative/passive design and retrofits; (iii) installation of super-efficient equipment and appliances; (iv) employment of smart systems; and (v) a switch to clean energy technologies for on-site building equipment and power generation. The application extend of these technologies has a very important impact on the reduction of GHG in the future. There are many kinds of building energy-saving technologies, in which the most important innovative technologies are the following sorts.

Semiconductor lighting technology (LED): Applicable to industrial plants, office space, home, and road lighting, the energy-saving rate per unit is 60% and the investment is 2,500–4,000 Yuan/tce.

Regional combined heat and power technology: BCHP technology provides an overall solution for large-scale public building energy supply, which can save 20–30% energy consumption. Energy cost decreases by 30 Yuan/m^2, and investment increases by 120 Yuan/m^2.

6 Barriers and Challenges for Diffusion of LCTs to Achieve INDC Targets

6.1 China Can Hardly Achieve INDC Targets Following the Example of the Development Model of Developed Countries

Taking identical development level (at 2005 constant price GDP per capita) as reference, the carbon emission and energy consumption in developed countries, including USA, Canada, the European Union (EU), and Japan, were compared.

Figure 6 illustrated the increasing mode of carbon emission in developed countries; i.e., as economic grows, GDP per capita grows, and then the carbon emission per capita initially grows rapidly. After reaching a certain value (different countries may have different values), the carbon emission per capita stops increasing with the GDP per capita growth; in some cases, it even shows a downward trend. For developed countries such as USA and Canada, carbon emission per capita is about 15–20 t/a; for EU, this value is 7–10 t/a. Japan has similar situation to EU, but with less carbon emission at the same economic level. At present, energy efficiency level in China is much lower than that in EU and other developed countries. However, without timely and effective measures to improve energy efficiency and control energy consumption and CO_2 emission, it is very difficult for China to catch up to the level of EU and Japan (He 2016). If China aims

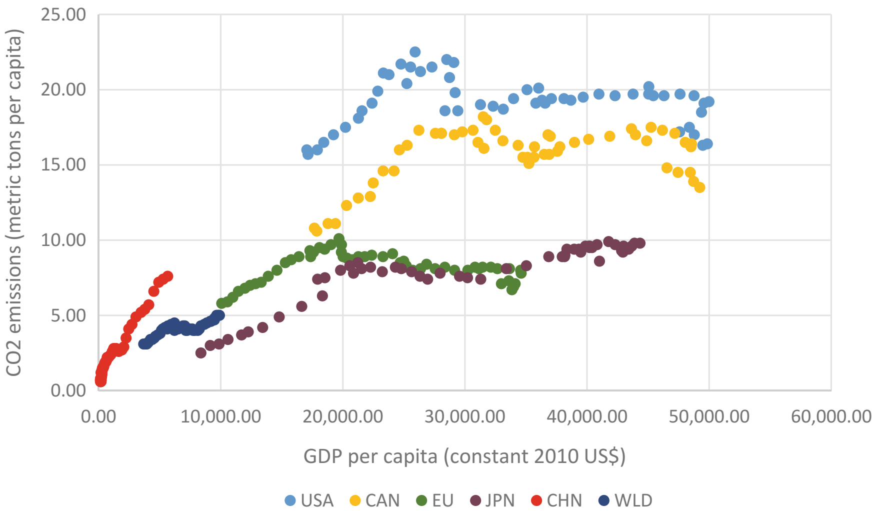

Fig. 6 Comparison of carbon emission in typical developed countries. *Source* (The World Bank 2016). Note: *USA* United States America, *CAN* Canada, *JPN* Japan, *CHN* China, *WLD* World

at Japan's mode instead of EU's mode, significant effort is required. It can only be achieved by improving energy efficiency significantly and effectively controlling the total amount of CO_2 emission and energy consumption.

6.2 *Imperfect Technical Standard System*

Policy coverage is limited. For some industries, development policies, industry access conditions, standard limits, and compulsory policies related to energy conservation and emission reduction are not released. Current energy consumption limit standard has not covered all of the high energy-consuming products. Moreover, for some key industries, update cycle of standard is too long to adapt the demand of recent development, resulting in weakened impact of relevant standards and leading to the existence of outdated technologies (Du 2016).

Due to the incompleteness, the current index system fails to clarify the complex of technology application and maturity, which confines the promotion of energy conservation technologies. Using only one or two index as a distinction of energy-saving technology may cause a confused division, which is not suitable for the popularization of advanced technologies. Taking demonstration projects selection as an example, due to the lack of evaluation index and disunion of index calculation method, some of the advanced technologies might be wiped off.

6.3 *Effective Economic Incentive Policies*

Firstly, some of the incentive policies are very strict, which weakens the initiative of enterprises. For example, during the period of the 11th Five-Year Plan, policy of substituting subsidies with rewards only applied to energy conservation projects with an annual energy-saving amount of more than 10,000 tce/a, and the actual annual amount of energy saving for the projects obtained government finance support reached 27,800 tce. Despite the threshold of energy-saving amount reduced to 5,000 tce/a during the 12th Five-Year Plan period, an extra restricted condition stated that only the enterprises with an annual energy consumption over 20,000 tce are qualified for the substitute subsidies with rewards, which limits the initiative of small enterprises not reaching the threshold.

Secondly, effective means of restraint in low efficiency and with high pollution industries are inadequate such as lack of corresponding tax control tools or inadequate regulation to resources. Taxes that can protect ecological balance such as carbon tax or energy tax are severely insufficient or even absent. There is no legislation regarding environmental tax in China, which seriously affects the promotion of LCTs in related enterprises. Chinese government released a draft law of environmental protection tax for public comment in September 2016, in which the estimated levy of taxes is 1.2 Yuan per unit on air pollutants (Standing Committee of the National People's Congress 2016).

Besides, the Chinese government does not provide enough support to the application of LCTs at policy and financial level. LCTs require high initial investment, which calls for sufficient support from the government. In energy conservation transformation areas such as wind power, PV, and renewable energy development, it is difficult for enterprises to bear all the expenses without loan or other financial support from the government.

6.4 Serious Constraints in the Development of Renewable Energy

Integration and consumption of renewable energy is facing serious constraints and barriers. Some regions constrain power supply from renewable energy, which lead to serious problem of power-consuming. Direct reason is that renewable energy power has problem in power network convergence planning, construction layout, and coordinated development with other energy sources, while the long-term, deep-rooted reason is that the current power system no longer adapts to the demand of renewable energy development. Moreover, the protected acquisition of renewable energy is not truly implemented. Distributed energy resources are facing obstacles in many aspects, such as management, operation, and supervision standards. When setting the rules of price, credit and taxation for renewable energy, specialized policies considering the advantages, and characteristics of distributed energy still need to be established and perfected.

Funds supporting long-term development of renewable energy are not guaranteed. By the end of 2011, China has already established renewable energy development fund, but the funding sources are insufficient given the rapid development of renewable energy. Delay and shortage of electricity subsidies affect the fund chain of relative enterprises, which has a negative impact on the industry development.

6.5 Difficulties in Technology Transfer

According to the United Nations Framework Convention on Climate Change (UNFCCC), developed countries have the responsibility to implement technology transfer to developing countries, but the actual progress is not satisfactory. The reasons might lie in three following aspects. First, technology transferor prevents the rapid spread of LCTs in the concern of market share. Second, technology recipient also faces obstacles such as the lack of talent, high transfer fees, scattered industrial structure, and imperfect policies and laws. Third, deviations exist in the implementation process of clean development mechanism (CDM). In most cases, only funds transfer (i.e., trade of carbon emission right) and no technology is transferred or exported.

Along with the continuous progress of China's enterprises, the gap of technology between China and developed countries is gradually reduced, which makes technology transfer more difficult (Qi and Zhang 2016). Developed countries take intellectual property protection as excuse and constantly increase the cost and threshold of technology transfer to China. In the process of introducing advanced technology, developing countries must abide the international treaties and also have to accept restrictive conditions made by developed countries.

6.6 Uncertainty in Technological Innovation

Low-carbon development mainly focuses on the popularization and application of the existing mature technologies. However, it also considers the spontaneous progress under the marketing learning curve, including continuous improvement of energy utilization efficiency in the terminal sectors, and lower cost of renewable energy power generation. However, due to the uncertainty in the technological innovation, in the LCTs scenario, actual situation in the future may have multiple possibilities. Energy saving is usually classified as scattered secondary investment and affected by concept of awareness, information asymmetry, and institutional mechanisms. In reality, even if the technology was proved advanced and mature in practice, it can hardly be fully populated, either replaced by more advanced technologies or replaced by higher energy consumption technologies with other competitive advantages. Particularly, unlike the first two industrial revolutions, the third industrial revolution has the trend of multipoint innovations and can be found in multiple fields including modern information, renewable energy, the fourth-generation nuclear power, combustible ice, and intelligent manufacture, showing an obvious characteristic of cross-field integration. Under this circumstance, there might be a revolutionary technological breakthrough to largely reduce the energy consumption and CO_2 emission, or labor will be massively substituted by machine that creates new section of energy consumption. These possibilities cast uncertainties to the energy consumption scenario in the future.

6.7 Contribution of Efficiency Improvement Maybe Under Expectation

There is a "rebound effect" in the energy saving, which means the efficiency improvement may bring new energy demand, offsetting the contribution of technical progress to some extent. Domestic and overseas theories and practical experiences show that technology progress will improve energy efficiency on the one hand, but it also promotes economic output growth on the other hand, which in turn increases the energy demand, making the contribution of efficiency improvement lower than expectation. Taking lighting needs, for example, in recent decades, along with the rapid development of lighting technologies, traditional thermal radiation sources (incandescent lamp, halogen tungsten lamp, etc.) were gradually replaced by gas-discharge source (fluorescent lamp, high-pressure mercury lamp, high-pressure sodium lamp, etc.) and electroluminescent light source (LED). Indicators as luminous efficiency and bulb's lifetime continued to upgrade, but due to the rapid growth of total demand of lighting, electricity demand kept elevating worldwide. In UK, for example, total demand for lighting increased by about 100 times from 1,900 to 2,000 and increased by 32 times in the recent 30 years, which indicated a continuous growth in lighting electricity demand. Energy efficiency in the future will keep improving along with the development of science and technology, but increasing personalized and diversified demand may cause new energy service demand, which will bring uncertain effect on the increase in energy demand of the whole society.

7 Meta-policy Analysis

7.1 Strengthening Low-Carbon Development, Achieving the INDC Target

From now on, if advanced energy-saving technologies, renewable energy, and other measures are promoted and extensively applied, China's CO_2 emission will achieve its peaking at around 2027. The commitment of "achieve the peaking of CO_2 emission around 2030" made by Chinese government is possible to achieve in advance. The peak value of CO_2 emission will be 10.9 billion tons. Compared to 18.3 billion tons in the reference scenario, the emission amount will decrease by 40.3%. After the peak year, CO_2 emission will steadily decline to 5.1 billion tons in 2050, which is 36% lower than that in 2010 (Fig. 7). China will make a significant contribution to deal with the global climate change.

In the LCTs scenario, China's CO_2 emission intensity of GDP (referred to as carbon intensity) will be reduced by 93% in 2050 compared to that in 2005 (Fig. 8). In the first step, carbon intensity will be reduced by 46% in 2020 compared to that

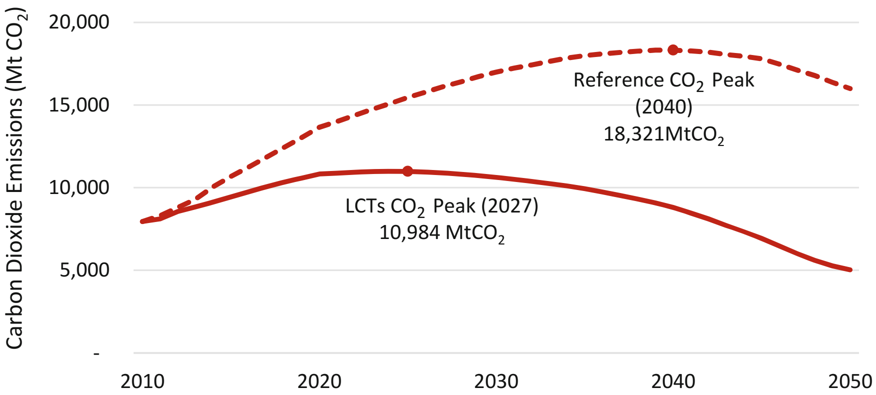

Fig. 7 Comparison of CO_2 emission between the LCTs scenario and the Reference Scenario (2010–2050). *Source* Authors

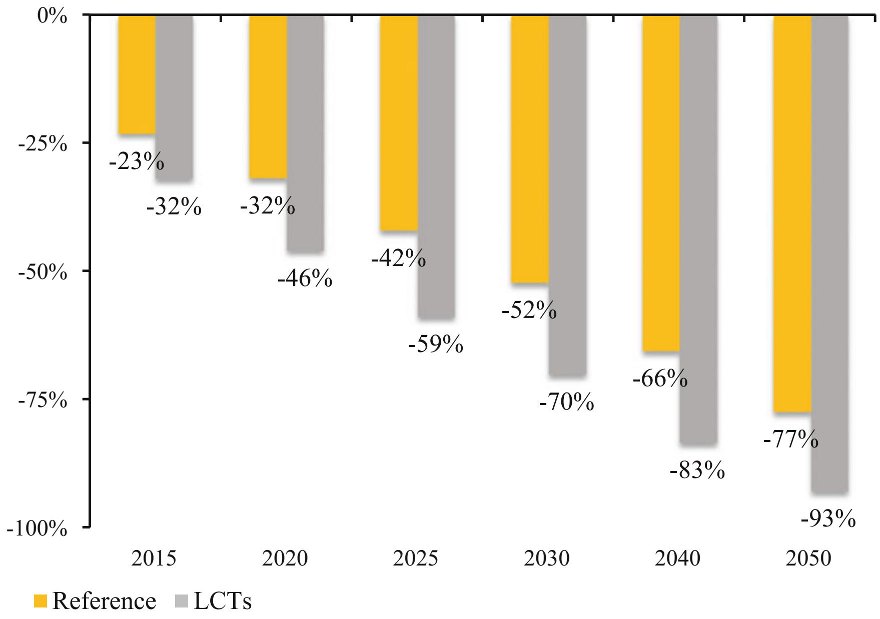

Fig. 8 Comparison of Carbon Intensity Reduction between the reference scenario and the LCTs scenario (2015–2050). *Source* Authors

in 2005, which is slightly more than the China's commitment made in 2008 (40–45%). In the second step, carbon intensity will be reduced by 70% in 2030 compared to that in 2005, which surpasses China's commitment (60–65%).

7.2 Applying Market-Oriented Approaches to Promote LCTs

In the LCTs scenario, CO_2 emission of industrial sector will reach the peak in the period of 2020–2025, with a total annual amount of 4 billion tons, and then decrease continuously. Combined heat and power (CHP) technology is a mature energy utilization technology, which is of great market potential in reducing fossil energy consumption and CO_2 emission. CHP power will increase from 250 billion kWh in 2015 to the peak of 610 billion in 2030, and then gradually reduce to 380 billion kWh in 2050. Due to the climate policy intervention or emission targets limitation, CCS in the industrial sector has certain potential, which mainly lies in steel and cement industries. The potential of CCS in steel and cement industries in 2025 will be 1.1 and 1.5 million tCO_2, respectively, and will increase to 5.7 and 6.5 million tCO_2 in 2050 (Table 7).

Since 2008, National Development and Reform Commission successively released six batches of "national key energy conservation technology promotion directory," involving 13 industries including coal, electric power, iron and steel, nonferrous metals, oil, chemical, building materials, machinery, light industry, textile, construction, transportation, and communications, with a total of 266 key energy-saving technologies. The promotion mode of efficient energy utilization technology is relative mature, while more means of marketization needs to be introduced in the future. First, product benchmark system should be integrated with government procurement catalogue. Dynamic energy efficiency evaluation system and standard should be established, and only the products reached a certain rating can be listed in the catalogue. Second, financial and tax incentive policies should be designed to increase subsidies to large renovation projects as pot furnace and high-efficiency motor, make elimination plan, strengthen the supervision system of access to the source, and set trade-in, reproducing subsidies and tax preference policies to equipment replacement or reproducing. Third, business model of energy performance contracting should be promoted.

Table 7 Key parameters of industrial sectors in the LCTs scenario

	Unit	2005	2020	2025	2030	2040	2050
Total amount of energy consumption	100 Mtce	12.3	21.5	22.8	22.0	19.4	16.0
Total amount of CO_2 emission	100 $MtCO_2$	27.4	39.7	41.3	38.5	30.8	21.6
CCS potential	Steel ($MtCO_2$)	0.0	4.11	10.59	18.55	37.76	57.39
	Cement ($MtCO_2$)	0.0	7.26	15.39	22.37	39.82	65.15
CHP	100 M Wh	0	4,320	5,940	6,130	5,430	3,770

Source Authors

7.3 Developing Non-fossil Energy Vigorously

China's total energy consumption will maintain an upward trend within a period of time. In the LCTs scenario, total energy consumption in 2020 and 2030 will be 4,868 and 5,248 billion tce, respectively. Figure 9 shows the change of power installed capacity over time in the LCTs scenario. In 2030, the proportion of non-fossil energy in the country's electricity consumption will reach 40%, increased by 17% compared to that in 2005; the proportion of coal-fired generation in the country's electricity consumption will be 39%, reduced by 38% compared to that in 2005. In 2050, renewable energy will provide 69% of the country's electricity generation, which means nearly three-quarter of China's electricity is provided by renewable energy sources. The proportion of nuclear power will increase to 14% in 2050, which indicates a substantial increase from 2005, when the proportion of nuclear power was only 1%.

The GHG emission peak of power sector in the LCTs scenario appears in 2030, with a GHG emission total of 4.9 billion tons, while in the reference scenario, the peak will appears in 2045, with a GHG emission total of 8 billion tons. The peak time in the LCTs scenario will be moved up by 15 years, and the emission total at the peak will be reduced by 39%. The total CO_2 emission of power sector in 2050 in the LCTs scenario will be 1.62 billion tons, only 83% of the emission total in 2005 (1.96 billion tons), and 4.7 billion tons less than that in reference scenario (as shown in Fig. 10).

Due to the scale effect and technological progress in renewable energy sources, the capacity cost of renewable energy will have a substantial downward within 20 years. Meanwhile, because of the little space of technology progress and almost saturated scale effect, the capacity cost of fossil energy has limited reduction space.

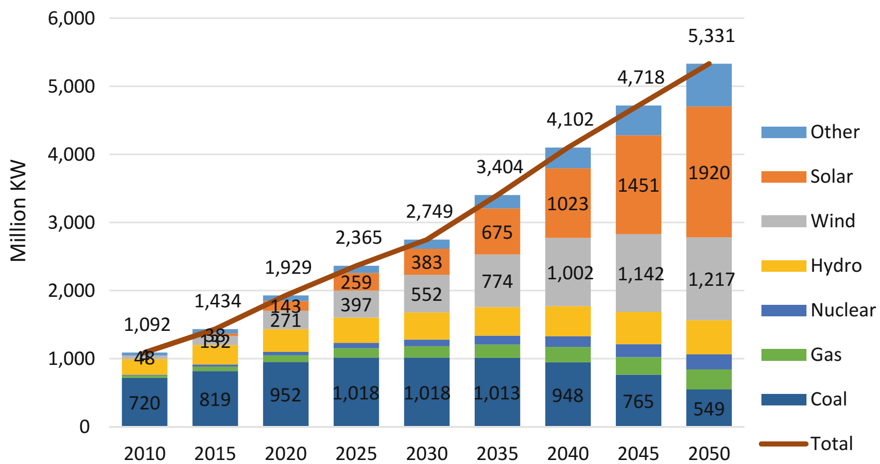

Fig. 9 Capacity structure in the LCTs scenario (2010–2050). *Source* Authors

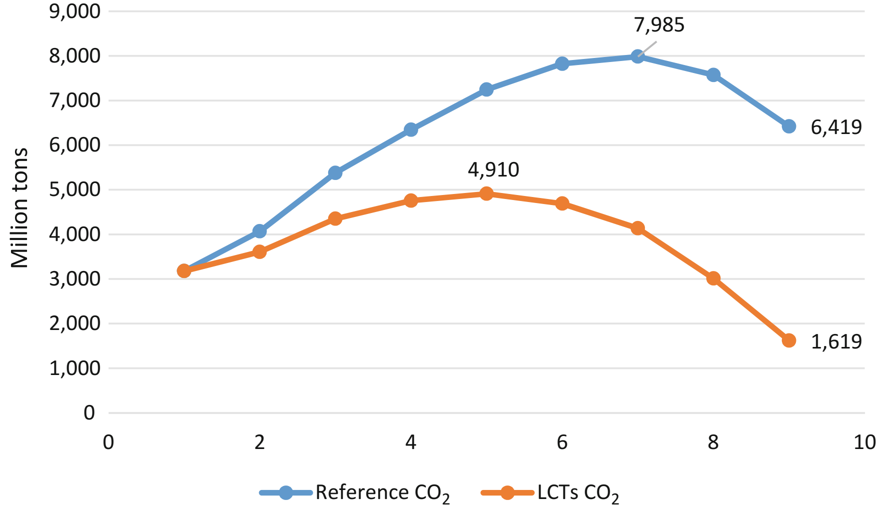

Fig. 10 CO_2 emission from power sector. *Source* Authors

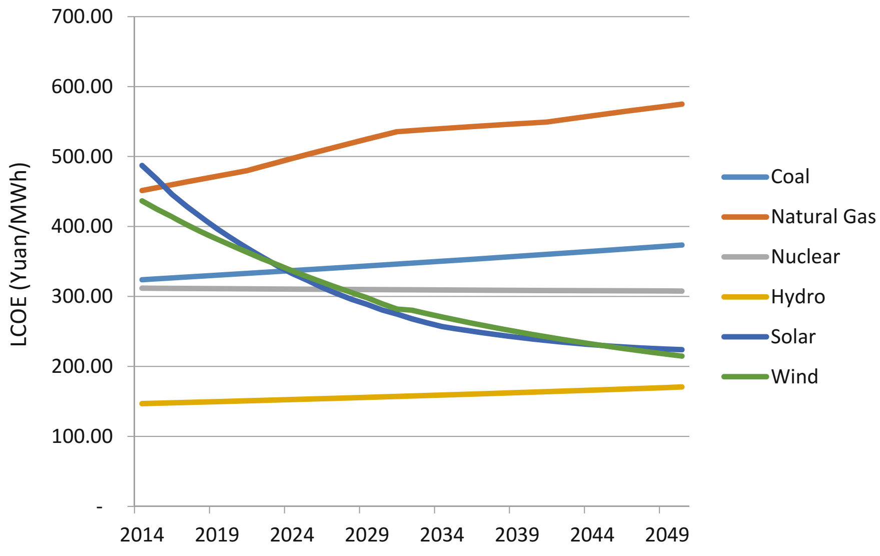

Fig. 11 Expected electricity cost by sources. *Source* Authors

Around 2025, the cost of wind power generation will be lower than the coal-fired power. Around 2035, the cost of PV power generation will be lower than the coal-fired power. These new changes will benefit the large-scale development of renewable energy sources such as wind and solar power (as shown in Fig. 11).

The cost of renewable energy sources and new energy technology has significantly declined; therefore, the promotion and support mechanism to new energy technology should be changed accordingly. First, gradual subsidy mechanism should be established. For the development of new energy, initial subsidies and electricity quantity subsidies should be combined. The initial subsidies should be strengthened to ease the financial pressure; then, the electricity quantity subsidies are gradually reduced as the technique improves. Second, incentive mechanism of ensured electricity should be implemented. Higher priority of electricity insurance should be given to the enterprises that built new energy power generation system as orderly power management (peak load shifting or averting) is implemented. In order to achieve the double control target, power generation using new energy sources can be deducted from the annual usable energy index. Third, cross-border cooperation will be explored. New energy development will be combined to new format and new system. For example, Internet Plus can be used to promote micro-energy network. In addition, promotion of PV and wind power poverty alleviation projects will be accelerated, thanks to the distributed power generation technology and profit support system.

7.4 Decoupling Oil Consumption from Energy Use in Transportation Sector

Reducing the dependence on oil, increasing the share of electricity and renewable energy in energy consumption structure, will significantly reduce the demand for fossil energy. Compared to the reference scenario, optimized transportation fuel structure can reduce the energy demand by 9%, which accounts for 18% of the total energy-saving potential in transportation sector.

For vehicle fuel substitution, in the short and mid-term, the majority succedaneum will be hybrid electric vehicles and natural gas vehicles, while in the long term, along with the technique maturation and cost reduction of plug-type electric cars and pure electric vehicles, the energy efficiency will be further improved. Natural gas has relatively lower price and is cleaner than diesel. It greatly contributes to regional reduction of CO_2 emission and environmental pollution. With increasingly rigorous environmental emission standards and requirements, natural gas vehicles are expected to have promising application in the future. In 2025, natural gas will account for 10% of total energy consumption in road transportation sector, besides ships has also begun to use natural gas. In the LCTs scenario, 8% vehicles will be natural gas vehicles, which are mainly heavy-duty trucks and city buses.

Given that the share of renewable energy in power network will continue to increase in the future, carbon emission reduction effect in the lifetime of electric vehicles will become more obvious, which will also benefit energy saving. Compared to traditional gasoline vehicles, electric vehicles can save over 35% in energy consumption and 20% in CO_2 emission. In the LCTs scenario, for private cars, in the years of 2030, 2035, 2040, and 2045, the penetration rate of electric cars in new vehicles will be 55, 70, 85, and 100%, respectively. For taxis, in the years of 2030, 2035, and 2040, the penetration rate of electric cars in new vehicles will be 70, 94, and 100%, respectively. In the LCTs scenario, energy consumption of transportation sector is 47% lower than that in the reference scenario, the proportion of oil will reduce to 50%, and the emission of CO_2 slows down and will reach its peak in 2035 (as shown in Fig. 12).

7.5 *Execute Energy Efficiency Limit Standards, Strengthening Cross-Sectors Comprehensive Energy-Saving Effect*

Providing same architectural service, the higher energy efficiency in the energy system and equipment of heating, cooling, hot water, lighting, household appliances, and office facilities, the less energy consumption at the end-use. Along with the continuous improvement of the social economic development and people's living standards, the inventory of all kinds of energy equipment in commercial and residential sectors will continue to grow in the future. Therefore, improving efficiency of energy service equipment is a key aspect to achieve CO_2 emission peak target. By far, a variety of energy equipment in commercial and residential has put into use of super-efficient products, which significantly improved the efficiency level compared to ordinary products. For example, organic light-emitting diode (OLED) television can save 30% of power than current liquid crystal display

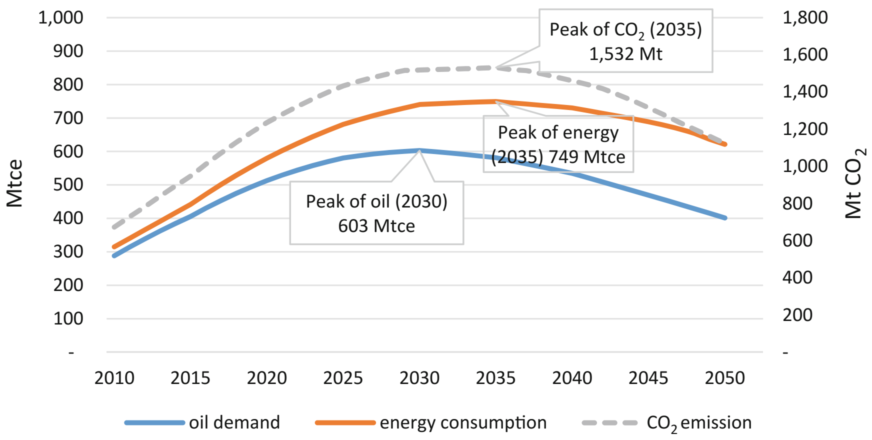

Fig. 12 Peak time of oil demand, energy consumption, and CO_2 emission in transportation sector. *Source* Authors

(LCD) television. However, the penetration rate of this super-efficient energy equipment is still very low right now; hence, the promotion of this efficient energy equipment needs to be accelerated for commercial and residential sectors to reach the CO_2 emission peak as early as possible.

Low-grade waste heat in the industrial production process is usually difficult to recycle and use in the production process itself, but it can be used as building heating source, thus reducing the fossil energy consumption in building heating, especially coal consumption. China has rich industrial waste heat resource, and only the low-grade industrial waste heat resource in Beijing–Tianjin–Hebei region can meet the needs of building heating of the region in the next 10 years. By far, several successful cases of low-grade industrial waste heat in China have shown great energy-saving potential and economic benefits. For example, Qianxi County in Hebei Province makes rational use of low-grade waste heat resource produced by two steel companies to meet the heating requirements of 3.6 million m^2 in the county, alleviating the financial pressure on the country government of heating subsidies.

In the LCTs scenario, the end-use energy consumption growth in commercial and residential sectors will slow down sharply and will reach the peak before the year of 2039. In 2050, the end-use energy consumption will be 1,622 million tce, decreased by 51% compared to the reference scenario. Emissions increase slowly from 2010, peaking by 2029 at a level of 2.8 billion tons. CO2 emissions decrease thereafter. In 2050, CO_2 emissions drop by 46% compared to 2010 emissions (as shown in Fig. 13).

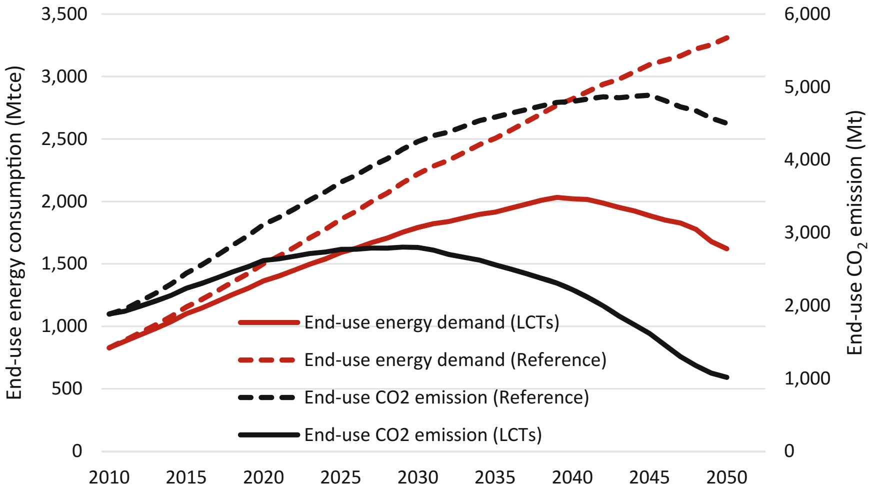

Fig. 13 End-use energy demand and CO_2 emission of commercial and residential sectors under different scenarios. *Source* Authors

7.6 *Economic, Environmental, and Social Benefits of Low-Carbon Development*

Ours study demonstrates that the LCTs scenario is feasible in technology, reasonable in economy, and acceptable to the society. Model estimation indicates that from 2010 to 2050, the LCTs scenario can save 56 trillion Yuan (in 2010 price) of energy cost according to the net present value calculation, and the total investment is 35 trillion Yuan (in 2010 price). It means the net profit will be 21 trillion Yuan (in 2010 price) (as shown in Fig. 14), assuming a real 5% discount rate. This calculation includes capital, operating, and maintenance costs, but excludes implementation costs as well as all externalities. The results show that although the development of LCTs requires a lot of investment in introducing advanced energy-saving technologies and promoting renewable energy development, the extra investment can be compensated by reducing energy expenditure and using cheaper renewable energy electricity and thus obtain more economic returns.

In addition to economic benefits, low-carbon development can reduce pollution from the source and bring environmental and social benefits by improving environment and health level. According to the estimates, in 2011, China's environmental losses accounted for 5–6% of China's GDP, equivalent to 2.35–2.82 trillion Yuan. In 2014, the Environmental Planning Research Institute attached to the Ministry of Environmental Protection released a report named Study on External Cost Accounting and Internal Chemical Project of Coal Environment. The report

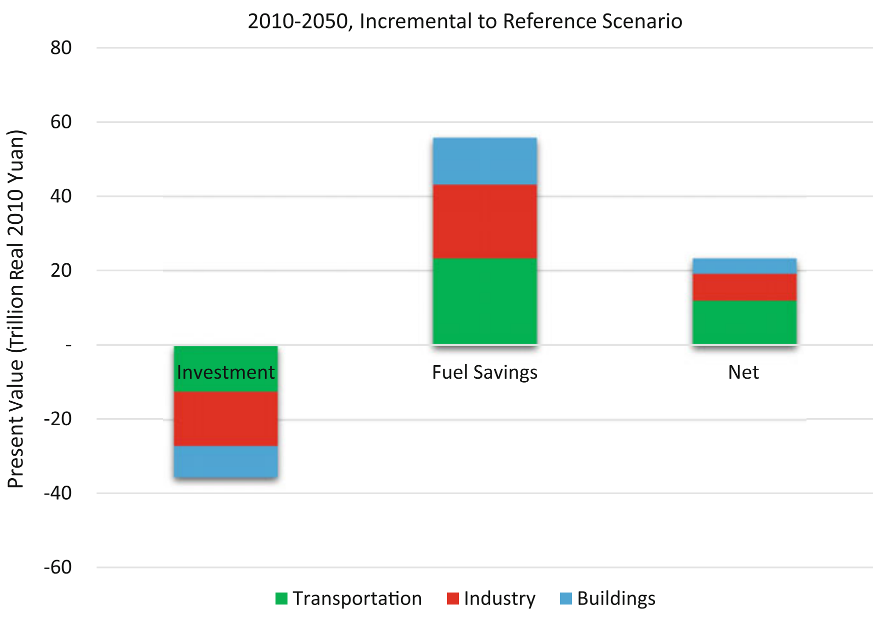

Fig. 14 Net present value of LCTs scenario. *Source* Authors

indicated that the loss of residents' health and mine workers' health caused by air pollution is 305.1 billion Yuan in 2010. Compared to the reference scenario, environmental loss and residents' health loss in the LCTs scenario will be significantly reduced, which has obvious environmental and social benefits.

8 International and Regional Collaborations

8.1 Existing Collaborations

China–International organizations

China has established many multilateral cooperation mechanisms with international organizations, such as Asia-Pacific Economic Cooperation (APEC), International Energy Forum (IEF) and G20. Energy efficiency improvement and the development of renewable energy are important issues in the energy cooperation between APEC and G20. The leaders' summit reaches consensus on low-carbon development and pledged to maintain a fair and open market and remove trade protection and restriction measure that may impede low-carbon development. Although these communiqués do not have mandatory requirements, it gives a trend of global low-carbon development.

China–USA

From 2014, climate change has become a pillar of the China–US bilateral relationship. And under the China–US Climate Change Working Group, China and USA have launched action initiatives on vehicles, smart grids, carbon capture, utilization and storage, energy efficiency, greenhouse gas data management, forests, and industrial boilers. Through the China–US Clean Energy Research Center, cooperation strengthened in carbon capture and storage technologies, energy efficiency in buildings, and clean vehicles.

China–European Union

The mechanism between China and European Union includes the following: the China–EU Energy Conference, China–Europe High Level Energy Working Group, China–Europe Energy Dialogue, and the EU–China Summit are the main official channels facilitating China–Europe's clean energy cooperation. EU–China energy relations began to flourish in 2005 with the launch of the official EU–China energy dialogue in the same year. There are six priority areas of China–EU energy cooperation: renewable energy, smart grid development, energy efficiency in the building sector, clean coal, nuclear, and energy law.

China–Association of Southeast Asian Nations

China and ASEAN have formed cooperative relationship in renewable energy sector and energy efficiency improvement. ASEAN plus China (10+1) Energy Cooperation and ASEAN plus China, Japan and Republic of Korea (10+3) Energy Cooperation are two key multilateral cooperation mechanisms. Through China-ASEAN Technology Transfer Center (CATTC), China and ASEAN member states made great achievements in the field of energy technology transfer. In energy sector, CATTC focus on the cooperation of solar, wind, small hydro, and biogas. In 2014, China and ASEAN jointly stated China–ASEAN New and Renewable Energy Action Plan (the Action Plan). The Action Plan is designed to boost joint research, technology and product demonstration, personnel training, business matchmaking, and academic exchange activities between China and partner country in the field of new and renewable energy, thus upgrading technology level, accelerating the new energy industry, optimizing the energy mix, and addressing climate change.

8.2 China's Policy Experience and Best Practices

China has made great achievements in low-carbon development, and China's policy experience and practice can be used as reference for regional countries.

8.2.1 China's Low-Carbon Development Policies

Besides setting and enforcing high-level low-carbon targets, Chinese government also implements and manages specific policies and programs to improve energy efficiency in key focus areas. Recent policies announced by the Chinese government include the following:

- Top Runner program: China is implementing a Top Runner program, which sets dynamic energy efficiency targets for a range of products. Targets are based on the highest efficiency models on the market, assessing the scope for further efficiency improvements in consultation with product manufacturers and then setting a schedule for manufacturers to reach the new efficiency benchmark. The program will begin by setting efficiency benchmarks for household appliances and consumer goods. Its scope will expand to energy-intensive sectors and public buildings. In industry, top runner benchmarks will be set for industrial products. Public buildings will face rising standards for energy consumption based on their building type. The program will be prescriptive and product-based, meaning that buildings will need to increasingly adopt high-efficiency technologies and products.

- Guidelines for sustainable development: The government has issued five principles to advance an "ecological civilization." Principles particularly relevant to energy efficiency include reorienting urban development patterns to limit sprawl, improving resource use and efficiency, and promoting technical innovation and structural change in the Chinese economy. To achieve the principles, the government has detailed such tasks as shutting down inefficient industrial capacity and prohibiting the resale and transfer of inefficient technologies to less developed regions of China.
- Regional carbon emission intensity decomposition: During the 11th and 12th FYP periods, 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, provincial governments put forward the energy-saving target of various regions.
- Practice of low-carbon city: Many Chinese cities strive to be members of "low-carbon cities" by making plans and setting up goals for local low-carbon development (Su et al. 2016). Currently, 6 provinces and 36 cities have been selected to be the low-carbon pilots in China, and the pilot project of low-carbon city has covered most of regions in China. Besides these pilot cities, a number of Chinese cities have also taken construction of low-carbon city into practice with different focuses. Some cities set up the overall low-carbon targets and planning, some conduct the low-carbon management, some establish the low-carbon demonstrative areas, and some pay attention to specific fields including sustainable energy, ecological industry, green transportation, green building, and low-carbon life.
- Emission trading scheme (ETS): In late 2011, the Chinese government appointed seven pilot carbon emission trading centers across the country, including two provinces (Guangdong and Hubei) and five cities (Beijing, Tianjin, Shanghai, Chongqing, and Shenzhen). In the pilot ETS, each province sets its own cap and decided which sectors it covered. For example, transport is included in Shanghai's ETS but not in the others. Pilot ETS carried out some preparations, including working out local laws and regulations, establishing MRV system, setting allowance allocation, and trading rules. The comprehensive and complete system frame of ETS pilots has been formed. By the end of 2015, seven pilot carbon emission trading programs have been launched, with more than 2,600 key emission enterprises in more than 20 industries, with annual emission quotas totaling about 1.24 billion tons of carbon dioxide equivalent. The cumulative trading of seven pilot carbon emission trading programs is about 67 million tons of carbon dioxide equivalent, which is worth about 2.3 billion Yuan (National Development and Reform Commission of China 2016b). China's pilot ETS traded increased from 16 million tons of CO_2 in 2014 to 33 million tons of CO_2 in 2015. China is planning to steadily extend the scheme to all 30 Chinese provinces starting in 2017, making China the

world's largest carbon market. Since the carbon dioxide emissions is a scarce resource controlled and issued by government, and its value is found and confirmed in the transaction in circulation, it can be regarded as a kind of production cost. ETS plays an important role in promoting social capital flows to the low-carbon field, and it is helpful for achieving the INDC targets (Zhao et al. 2016; Liu et al. 2015).

- Renewable energy law: In 2006, China's first renewable energy law came into effect. The goal of the law is to meet short-term energy needs while strengthening the long-term sustainable development objectives. The law aims to reduce air pollution, protect human health and the environment, strengthen and develop energy supply to rural areas, promote investment and development of renewable energy, etc. After four years of rapid change and expansion of China's renewable energy sector, an update to the original 2005 renewable energy law was adopted in December 2009, which came into effect on April 1, 2010. This update contained three main provisions: More detailed planning and co-ordination are to be required; provisions were strengthened to guarantee that electric utilities purchase all renewable power generated; renewable energy fund under the Ministry of Finance was strengthened and consolidated, which allows the Ministry to supplement the renewable energy fund from general revenues.

8.2.2 Policy in China Is Driving Expansion of the Market for Energy Efficiency

China has among the most comprehensive and aggressive sets of low-carbon development policies and programs in the world. These policies and programs have been a key driver of investment and improvement in low-carbon development.

Total public and private investment in low-carbon development totaled USD 249 billion in the first four years of the 12th FYP. The ERI estimates that this investment resulted in savings of 199 Mtoe. Low-carbon development measures were responsible for 47% of the progress toward the reduction in energy intensity. The breakdown of this four-year total investment was USD 29.82 billion (12%) from the central government, USD 6.88 billion (2.8%) from regional governments, and USD 211.82 billion (85%) from the private sources. Figure 15 illustrates that the amount of investment rose year-over-year between 2011 and 2014.

In 2015, the central government spent USD 6 billion on low-carbon development policies and programs, down from USD 9 billion in 2014. This decrease signifies that China is shifting from government incentives toward private sector investment.

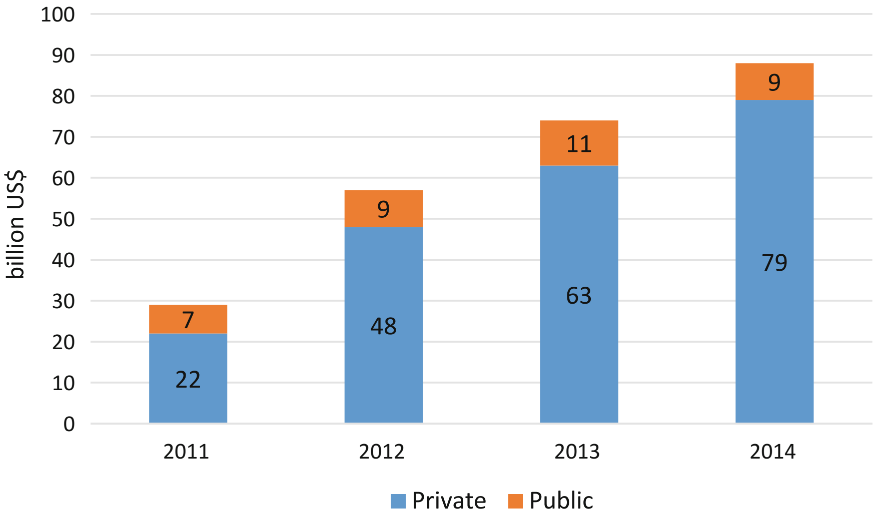

Fig. 15 Financial investment in low-carbon development by source (2011–2014). *Source* Authors

8.3 Policy Recommendations

Strengthening intergovernmental cooperation

Cross-border transfer of LCTs requires the mutual function of both government and the market, and either side alone can hardly bring a satisfactory effect. If in strict accordance with the market rules, the goal of enterprises is to maximize the profits. Enterprises will not consider the environmental benefits of technology transfer, and this is against the original intention of the United Nations Framework Convention on Climate Change original intention which is to protect the climate. Besides, since developing countries are constrained by financial shortage and cannot afford those advanced and expensive LCTs, they have to use the outdated technologies, which results in lock-in effect.

Governments should enhance international cooperation, build regional cooperation mechanism of energy in Asia, and promote ASEAN-East Asian energy integration design by means of collective wisdom and multilevel, multiagent exchanges and cooperation. Governments should encourage domestic enterprises to actively participate in the cooperation of LCTs transfer and provide relevant information.

Promoting participation of private sectors

Enterprises are the main body of LCTs application, and they know their own requirement of the LCTs, which can well evaluate the cost and profit of technology transfer in the cooperation. Therefore, promoting participation of private sectors in

LCTs transfer has great importance. On the one hand, developed countries should issue policies and measures to encourage domestic enterprises and research institutes to transfer technologies to enterprises and research institutes in developing countries. These policies and measures will send a positive signal to the private sectors in developed countries and provide incentives for the private sectors to actively participate in the technology transfer to developing countries, which will deepen and expand international technical cooperation. On the other hand, governments should remove the barriers in the process of private sectors participating in the international technology transfer. In particular, the developing countries should improve the domestic suitability of environment, including enhancing legislative system, strengthening environmental regulations, protecting intellectual property rights, and providing assistance to the private sectors involved in international technology transfer, thus ultimately promoting private sectors in the developed countries to transfer their advanced LCTs to enterprises in developing countries.

Eliminating barriers to low-carbon development

For the sake of getting rid of financial difficulties, some countries taken measures to stimulate their economy. But some measures led to the rising of trade protectionism and the increasing of trade frictions and disputes. In order to reduce greenhouse gas emissions, transfer the costs of emissions reduction, and protect domestic products, the developed countries set up low-carbon trade barriers on high-carbon imports from developing countries. On the one hand, developed countries have formed carbon emission standards in their own interests, imposing carbon tariffs on products exported by developing countries, but these standards have not formed a universally accepted and unified standard in the international community. International standards on carbon emissions must not be unilaterally decided by the developed countries, but should be discussed by the developed and developing countries together. On the other hand, European Union and USA launched investigations into alleged Chinese dumping of solar panels, which seriously affect the development of China's solar PV industry and hinder the diffusion of LCTs.

Strengthening joint technology research and development

Although developed countries can carry out different kinds of executions to promote private sectors to transfer technology or environmental and technical assistance to developing countries, this is far from enough to promote international technology cooperation. A good practice is to establish Asian joint research center of energy technologies, to establish long-term mechanism of communication within think tank of different countries in Asia, and to strengthen the application and promotion of research findings from joint research and development. During of cooperation, both sides share research and development cost, take risks according to a certain proportion, and share intellectual property rights, to achieve the common goal of dealing with climate change. Advanced energy technologies have long research and development cycle, high risk, and large investment intensity, but under the circumstance of current economic globalization, with the effective allocation of production elements on a global scope, the trend of dealing with climate change and the development of cutting-edge technology make the joint research and development in low-carbon field possible.

Establishing innovative financing mechanism

Upfront investment of LCTs application is so large that we need to drum up the support of Asian Infrastructure Investment Bank, Asian Development Bank, and Silk Road Fund for LCTs and projects. Regional low-carbon development fund should be established to promote regional development and utilization of low-carbon resources and to improve the energy efficiency. The promoting function of innovative financing to LCTs cooperation should be employed, and existing financing tools and means should be used in the development and application promotion to LCTs, effectively improving the ability of developing technology transfer projects and attracting project financing from demand side. We should establish public–private partnership (PPP) to attract more public sectors and private sectors (enterprises and syndications, etc.) involving technology development and transfer, diversify the sources of funds, and promote enterprises as main body in technology transfer and advanced technology diffusion and introduction.

Promoting regional low-carbon technology transfer relying on the Belt and Road Initiative

A great number of developing countries in the region have an urgent demand for renewable energy technologies; energy conservation and emission reduction technologies. China has a batch of mature and practical technologies in the field of low-carbon development and has formed a relatively complete technical system in some key areas such as renewable energy and energy saving. Under the circumstance of the Belt and Road initiative and deepening international cooperation on industrial capacity, based on other countries' actual demand, through multiple ways such as foreign aid training, demonstration projects, and directly involved in the construction, China should promote its advanced technologies to other countries in the region. At the same time, China should strengthen the cooperation in the fields of fundamental research, application technologies, and capacity building with other countries in the region, pursuing the common interests. Besides, China should encourage enterprises and colleges to participate in the international cooperation, promote the business and academic communications between both sides, and deepen tripartite cooperation in technologies, products, equipment, and standards.

9 Conclusion

In December 2015, China made an international commitment to the realization of peaking CO_2 emissions around 2030, making best efforts to peak early, increasing the share of non-fossil fuels in primary energy consumption to around 20% by 2030, and lowering CO_2 emissions per unit of GDP by 60–65% by 2030 from the 2005 level. These goals in support of the Paris Agreement's aim to keep average global temperature increase to between 1.5 and 2 °C.

Realizing China's domestic and internationally pledged goals requires a significant departure from the country's historical patterns of energy consumption and supply. On the supply side, the maximum feasible share of commercially available LCTs will be adopted, such as clean coal power generation technologies, nuclear power, wind power, and solar PV. On the consumption side, cost-effective energy efficiency will be adopted in four major economic sectors—industrial, transportation, commercial, and residential. And China can get lots of economic, environmental, and social benefits from low-carbon development.

China has made great achievements in low-carbon development, and China's policy experience and LCTs can be used as reference for regional countries. Strengthening intergovernmental cooperation, promoting participation of private sectors, eliminating barriers to low-carbon development, strengthening joint technology research and development, and establishing innovative financing mechanism can help to accelerate the proceeding of INDC targets.

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