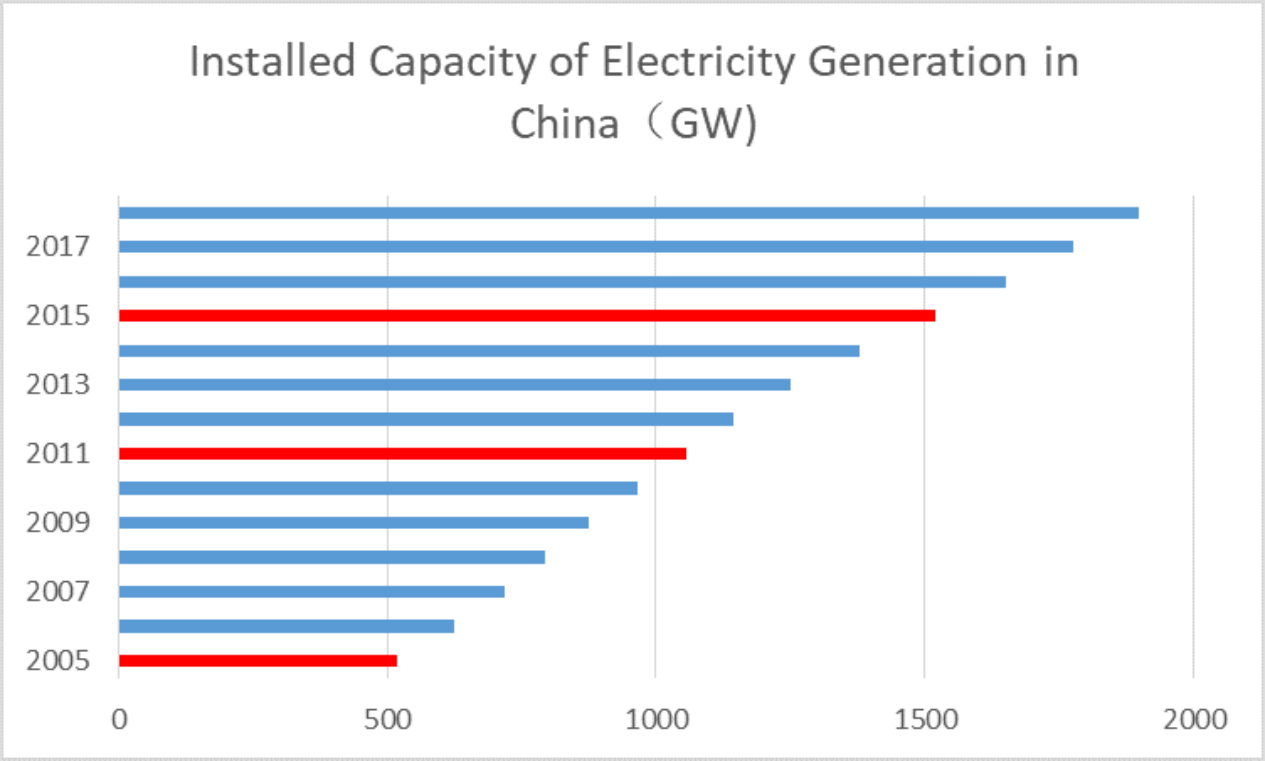
STATUS OF CHINA'S ENERGY SECTOR, RECENT TRENDS, AND CURRENT AND EVOLVING ENERGY POLICIES

REPORT OF THE CHINA WORKING GROUP TO THE REGIONAL ENERGY SECURITY PROJECT

WANG YANJIA, GU ALUN

NOVEMBER 24, 2019



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I. INTRODUCTION

In this Special Report, Wang Yanjia and Gu Alun summarized the status of China's energy sector and recent trends, and describe projections of China's energy future in the context of its energy policies. China's energy imports have been rising in recent years, and environmental, energy security, and other challenges related to energy use mean that China is actively seeking opportunities to cooperate on current and future transboundary energy projects with its neighbors and other nations.

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Banner image: Installed Capacity of Electricity Generation in China, 2005 through 2018, based on data from *China Electric Power Yearbook.*

II. NAPSNET SPECIAL REPORT BY WANG YANJIA AND GU ALUN

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Summary

China is the second largest economy, the largest energy consumer, and the largest GHG emitter in the world. After experiencing 40 years of rapid development, China plans to keep its GDP growth at a reasonable level but more moderate level for the coming decades. In order to improve local air quality and contribute to global GHG emissions reduction, China is encouraging a "switch coal to gas" program that has increased its gas import dependency to 40%. Together with China's high oil import dependence, the shift to imported gas raises a further concern regarding energy security. China is making great efforts to build friendly relationships with neighboring countries and oil/natural gas supplying countries. Meanwhile, China is investing a huge amount of capital in LNG terminals, transboundary oil pipelines, and oil refinery plants to secure the capacities to handle more imported energy in the future. Increasing the scale of energy cooperation is the focus of China's current regional energy cooperation efforts.

Although structural change both in the economy, as reflected in GDP statistics, and in the energy sector, has made progress in the past, the heavy manufacturing sectors and coal still play dominate roles in the economy and in energy supply, respectively. The fast growth in

output of energy-intensive products, such as steel, cement, has driven energy demand increases and, and as a result manufacturing is still the largest energy consumer among all sectors, even as the energy intensities of manufacturing of energy-intensive products has decreased significantly.

China is facing challenges to realize the transition from coal-dominated to clean/low carbon energy systems. This transition must meet the energy demands for economic and social development, reduce local air pollutant emissions, and honor the nation's commitment to addressing climate change simultaneously.

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1 Introduction

1.1 China's Physical, Demographic, and Economic Setting

China is located in the eastern part of the Asian continent, on the western Pacific Rim. It covers 9.6 million square kilometers of land. Additional offshore territory, including territorial waters, special economic areas, and the continental shelf, totals over 3 million square kilometers, bringing China's overall territory to almost 13 million square kilometers. In northeast Asia, China has common borders with Russia, Mongolia and the DPRK (Democratic People/s Republic of Korea, while China, the ROK (Republic of Korea) and Japan are neighbors facing each other across the sea.

By the end of 2018, China had a population of 1.39538 billion, 59.58% of which live in urban areas.[1] After the implementation of the 'one family one child' policy for two decades, many experts estimated that the population would reach its peak around 2030. The 'second-child' policy began to be implemented starting in 2016. The impact of this policy on population growth has obviously not yet shown up in the statistics shown in Table 1-1.

Table 1-1: Population Trends in China

	Birth rate	Growth rate	Population
	%	%	million
2005	1.24	0.589	1307.56
2010	1.19	0.479	1340.91
2015	1.207	0.496	1374.62
2016	1.295	0.586	1382.71
2017	1.243	0.532	1390.08

Source: China Statistical Yearbook 2018

China has become the second largest economy in the world since 2010. This achievement has been strongly supported by manufacturing industry development, especially the development of heavy industrial sectors. The structure of the Chinese economy is dominated by secondary industries, which has created problems such as environmental pollution, rapid growth in energy

[1] Source: Statistical Communique on the 2018 National Economic and Social Development

consumption, high dependence on energy imports, and huge GHG (greenhouse gas) emissions. The economic transition to a less resource-intensive and more sustainable economic mode has been happening in recent years through ongoing reforms and further opening to the outside policies. China is becoming a strong but maturing economy. Figure 1-1 shows the growth of GDP in total and by major subsector since 1978, the year that China started to reform. The industrial sector (part of secondary industry), dominated by manufacturing has grown fastest for years. The tertiary industries,[2] featuring high value-added and being less energy intensive per unit of economic output, has played a larger and larger role in the economy recently, as shown in Figure 1-2. If the structure of output is calculated using constant year 2015 prices, the share of tertiary industry in China's total GDP was more than 50% as of 2017.

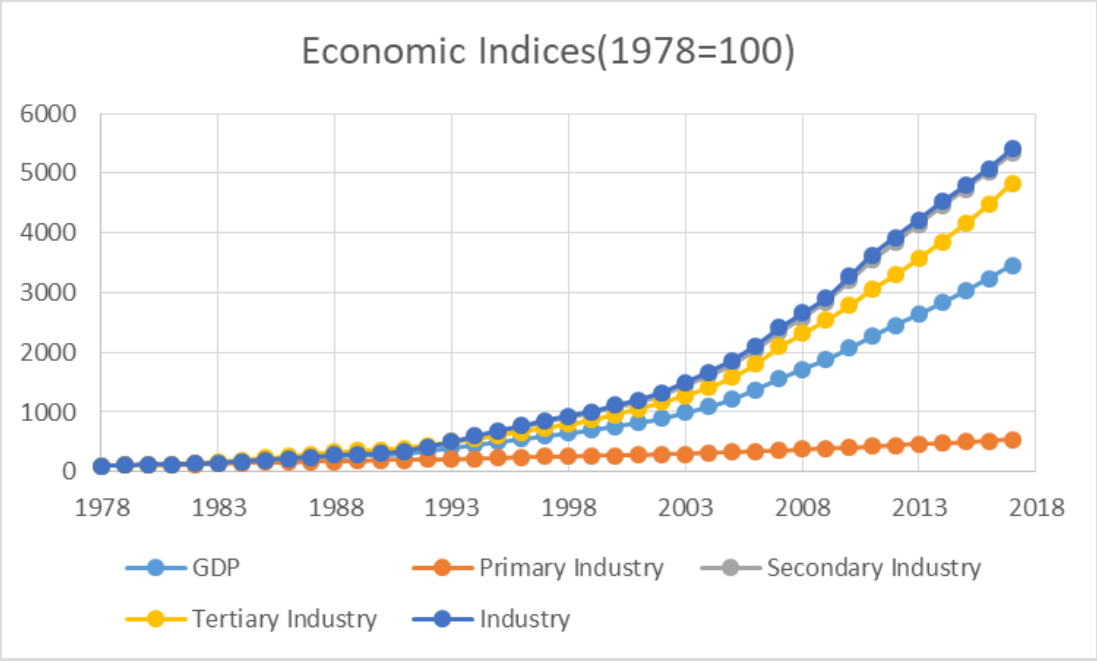

Figure 1-1: China's economic growth from 1978 to 2018

Source: China Statistical Yearbook 2018 (data are calculated at constant prices)

[2] Tertiary Industry includes the subsectors of Wholesale and Retail Trades, Transport, Storage and Post, Hotels and Catering Services, Information Transmission, Software and Information Technology, Financial Intermediation, Real Estate, Leasing and Business Services, Scientific Research and Technical Services, Management of Water Conservancy, Environment and Public Facilities, Service to Households, Repair and Other Services, Education, Health and Social Service, Culture, Sports and Entertainment, Public Management, Social Security and Social Organizations.

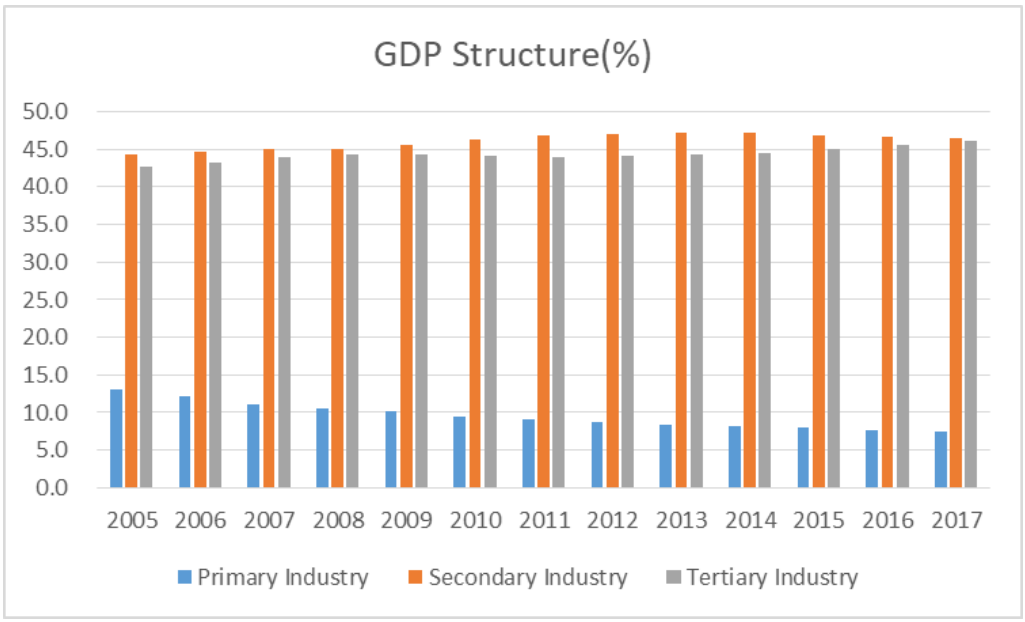

Figure 1-2: GDP Structure

Source: China Statistical Yearbook 2018 (data are calculated at 2010 constant prices)

1.2 Energy Demand and Supply in China

China consumed 4.49 Gt (billion metric tonnes) of SCE (standard coal equivalent), or 131.4×10^9 GJ, and produced 3.59 Gt of SCE or 105.1×10^9 GJ of primary energy in 2017.[3] The overall import dependence in China has risen to about 20%. Huge amounts of domestic coal resources supported the vast majority of China's energy demand for years. At present, the import dependence of China for both oil and natural gas are much higher than one fifth. Although China has made great efforts to develop clean energy production and keep domestic crude oil output stable, the extent to which coal dominates the energy mix has not changed significantly. Table 1-2 shows the latest data on primary energy production and consumption and the energy mix. The trend of less coal and more renewables (primary electricity) and natural gas is presented both in energy production and consumption. China's import dependency is generally getting larger and larger, although it did fall slightly between 2016 and 2017.

[3] Source: China Statistical Yearbook 2018. These data are estimated. 1 ton SCE=29.27GJ. The coefficient for conversion of electric power into SCE is calculated on the basis of the data on average coal consumption in generating electric power in the same year.

Table 1-2: Primary Energy Production and Consumption and Their Resource Mix

Year	Total Production of Energy and Its Composition					Total Consumption of Energy and Its Composition					Import dependence (%)
	Total Production (M tce)	Coal %	Crude oil %	NG%	Primary Elec. And Others %	Total Consumption (M tce)	Coal %	Crude oil %	NG%	Primary Elec. And Others %	
2005	2290.37	77.4	11.3	2.9	8.4	2613.69	72.4	17.8	2.4	7.4	12.4
2010	3121.25	76.2	9.3	4.1	10.4	3606.48	69.2	17.4	4	9.4	13.5
2015	3614.76	72.2	8.5	4.8	14.5	4299.05	63.7	18.3	5.9	12.1	15.9
2016	3460.37	69.8	8.2	5.2	16.8	4358.19	62.0	18.5	6.2	13.3	20.6
2017	3590.00	69.6	7.6	5.4	17.4	4490.00	60.4	18.8	7.0	13.8	20.0

Source: China Statistical Yearbook 2018

The primary energy and electricity consumption per capita were 3.16 SCE and 4446 kWh, respectively, in 2016, with annual growth rates of 4.2% and 8.0% from 2005 respectively.[4] The consumption level has passed the world average but is still much lower than the OECD average, as shown in Table 1-3. Energy demand per capita will definitely continue to increase in the near future.

Table 1-3: Comparison of Energy Consumption per Capita (2016)

	Total Primary Energy Consumption (toe/capita)	Total Electricity Consumption (kWh/capita)	Source
China	2.21	4446	China Energy Statistical Yearbook 2017
China	2.14	4290	IEA Key World Energy Statistics
World	1.85	3110	
OECD	4.11	8048	

1.3 Key Energy Policy Issues for China

Based on China's long-term strategic objectives and five-year planning targets, the energy policies of China focus on ensuring attainment of those targets. Current energy policies are intended to address the following two questions:

- How to realize the transition from coal dominated to clean/low carbon energy systems? The transition must meet the energy demands for economic and social development, reduce local air pollutants emissions and honor the commitment of climate change simultaneously.

[4] China Energy Statistical Yearbook 2017

- What can the energy sector do to help build a community with a shared future for mankind?

The key energy policy issues are:

- Managing total energy consumption by using energy efficiently;
- Reducing coal consumption by switching to renewables and natural gas;
- Improving the performance of renewable energy projects by deploying various technical measures;
- Encouraging international cooperation by exploring the possibility of transboundary energy system construction.

1.4 "Road Map" of Remainder of Report

Following this introduction, the next two chapters present China's current status and recent trends of energy demand and supply respectively. Chapter 4 provides an analysis of China's electricity supply sources and technologies in detail. Chapter 5 describes recent and current energy policies in the areas of energy security, GHG emissions reduction, regional air pollution reduction, and other environmental considerations. These policies will shape the future energy consumption and production. In the succeeding chapter on China's involvement in discussions on regional energy sharing, the report introduces the main considerations of regional energy cooperation. The final chapters propose future energy pathways for China to be developed and evaluated using the LEAP (Long-range Energy Alternatives Planning) modeling tool, and summarize the conclusions of the Report.

2 Energy Demand in China—Current Status and Recent Trends

The policies of energy efficiency improvement, economic structure adjustment, GHG mitigation and others have great impacts on energy demand. Although China's total energy demand grew from 2.61 Gtce (billion tonnes of coal equivalent) in 2005 to 4.36 Gtce in 2016, the annual growth rate of energy consumption has declined significantly in recent years, as shown in Figure 2-1. The great efforts that have been made to adjust the nation economic structure have changed the pattern of final energy consumption by sector as shown in Figure 2-2. Residential consumption increased by nearly two percentage points of the national total, and the service sector[5] increased by three percentage points, while the share of industry in final consumption declined about 5.6 percentage points from 2005 to 2016. Even with this reduction, however, industry remains the largest energy consumer among all sectors.

Industry has three components in energy statistics: Mining & Quarrying, Manufacturing, and Electric Power, Gas &Water Production & Supply. The final energy consumption of manufacturing accounted for 85% of total industrial final consumption in 2005. This share increased to 89% in 2016. Figure 2-3 shows the final energy consumption share of five

[5] Services include Transport, Storage and Post; Wholesale, Retail Trade and Hotel, Restaurants and others.

traditional heavy industrial subsectors. These subsectors consumed 78% of industrial energy use in 2016, having grown from 75% in 2005. Light industry may contribute more to GDP, but from an energy consumption point of view, the structure of manufacturing remains unchanged, or has even become somewhat more skewed toward heavy industry than it was before.

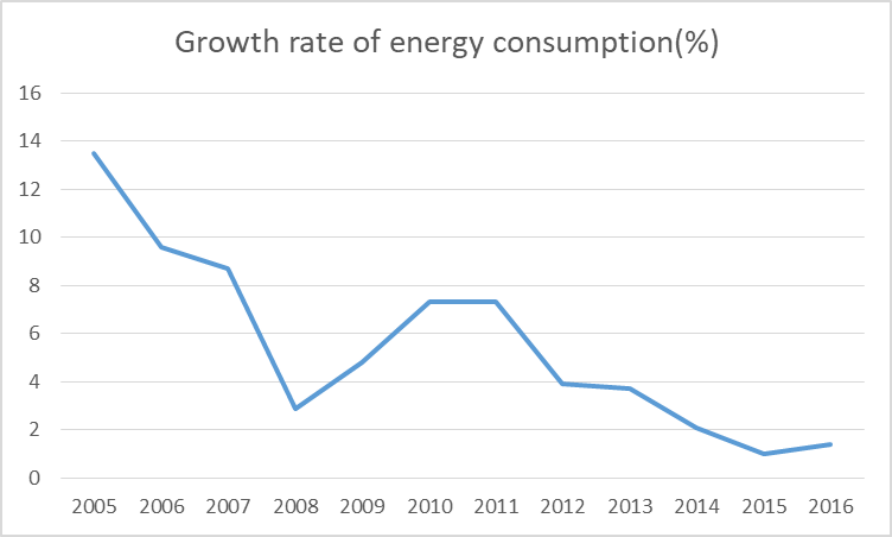

Figure 2-1: Energy Consumption Growth Rate since 2005

Source: China Energy Statistical Yearbook 2017

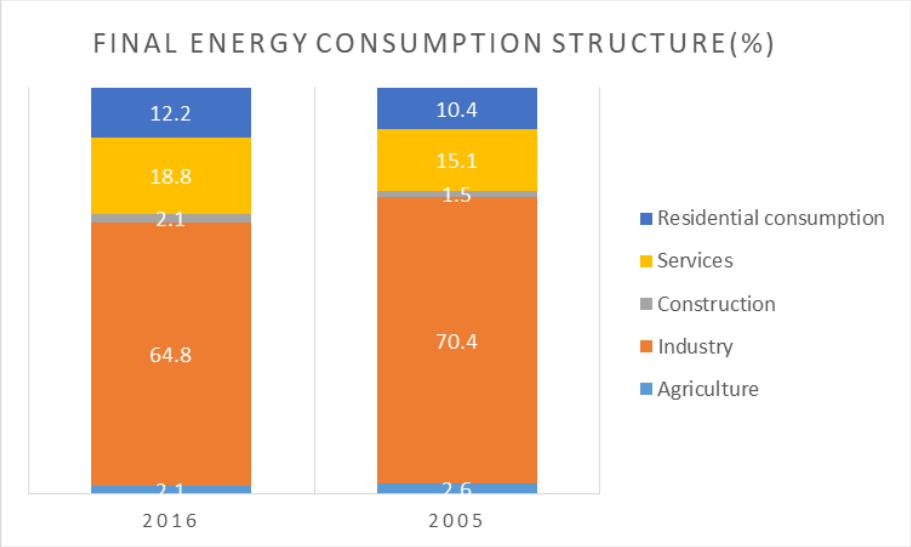

Figure 2-2: Final Energy Consumption Structure by Sector （Calorific value calculation）

Source: China Energy Statistical Yearbook 2017 and 2014

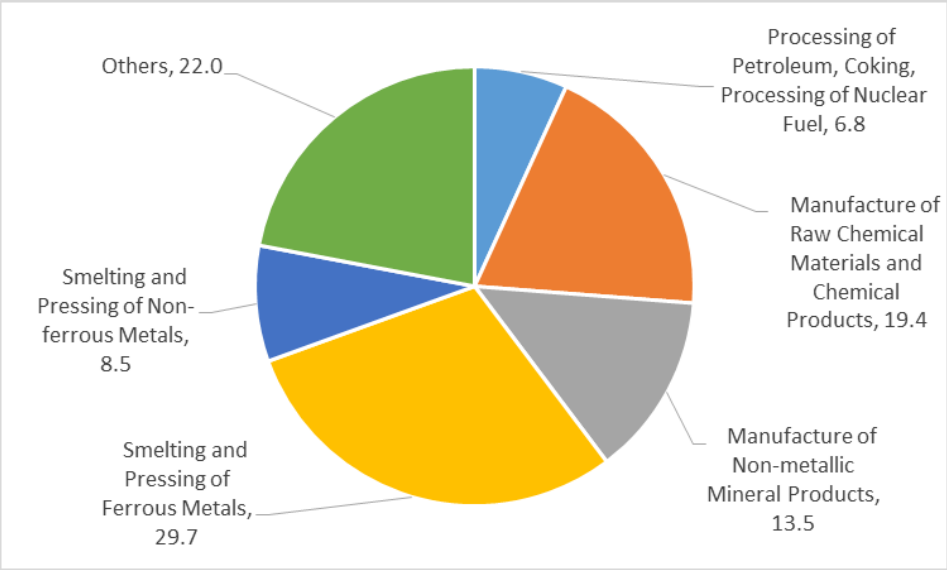

Figure 2-3: Main Industrial Energy Consumers and their Share in Final Consumption (%, 2016)

Source: China Energy Statistical Yearbook 2017

Table 2-1 shows that the outputs of selected energy-intensive products has increased tremendously in recent years. Meanwhile, the energy intensities of manufacturing these products has decreased significantly as well. Most of the outputs, however, increased faster than the efficiency improvements in the subsectors, resulting in overall increases in energy demands

.

Table 2-1: Selected Products' Output and Energy Intensities

Product	Output (10k ton)		Growth	Average Energy Intensity (kgce/ton, kWh/ton)		Growth
	2005	2016	2016/2005	2005	2016	2016/2005
Steel	35324	80761	2.29	732	640	0.87
Cement	106885	241031	2.26	149	135	0.91
Ammonia	4596	5708	1.24	1650	1486	0.90
Ethylene	756	1781	2.36	1073	842	0.78
Aluminum	767	3187	4.16	14575	13599	0.93

The recent development of energy consumption in the service industries and the residential sector presents a similar trend to that of industry, that is, rapid growth accompanied by a shift away from coal use. The final energy consumption of the service industries increased from 291 Mt SCE in 2005 to 600 Mt SCE in 2016, more than doubling in a decade. The final energy

consumption of the residential sector increased from 200 Mt SCE in 2005 to 389 Mt SCE in 2016. The share of coal in total final consumption decreased while the share of electricity, natural gas and other clean energy forms increased both for the service sector and for residences. As the fleet of private cars in China has grown, the share of oil consumption in the residential sector has increased 9 percentage points while the share for the service industry decreased 5 percentage points from 2005 to 2016, as shown in Figure 2-4.[6] The ownership of private vehicles increased from 18.48 million in 2005 to 207.3 million in 2018.

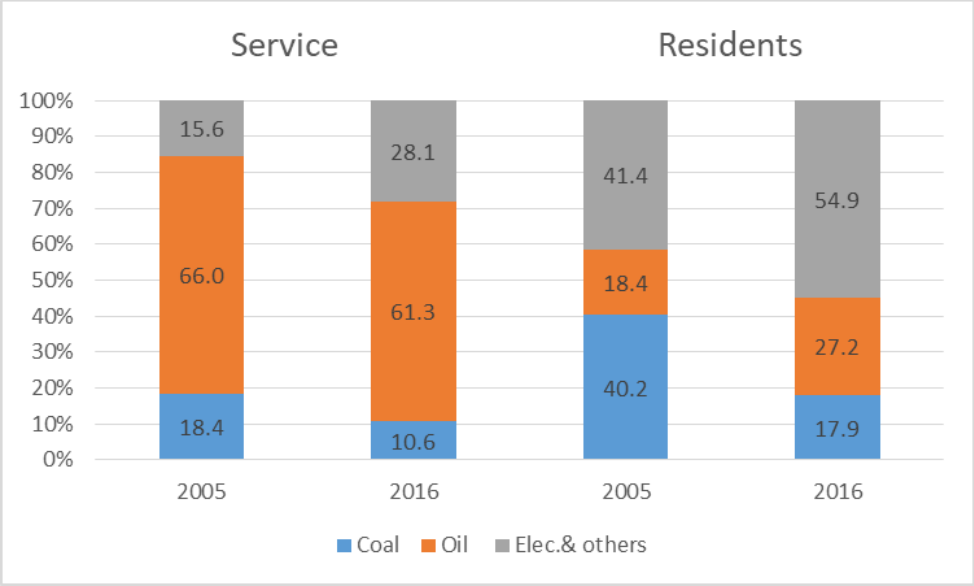

Figure 2-4: Final Energy Consumption Mix for Service Industry and Residents

3 Primary Energy Supply in China—Current Status and Recent Trends

As mentioned in Table 1-2, about one fifth of China's energy demand is met by imported energy; the rest being met by domestic production. Following more than two decades of sustained growth, the total primary energy production in China has decreased since 2014, as shown in Figure 3-1. Emissions reduction policies are the main driving forces causing the decrease. Various energy resources, however, present different trends.

- Raw coal: affected by price at international and domestic markets, China's imports of raw coal jumped in 2009 to three times the level of the year before. Since then the volume of imported coal continued to grow until 2013, as shown in Figure 3-2. Meanwhile, export coal volumes continuously decreased, with coal exports currently kept at less than 10 million tons

[6] Private vehicle transport is included in Chinese energy statistics as part of the residential sector, with the exception of fuel consumption by privately-owned vehicles used for economic production activities, such as trucks used by farmers to bring produce to markets, which is covered in fuel consumption statistics in other sectors, such as Agriculture.

for trade purposes. The import dependence of coal is below 10%. Considering the domestic resource availability and production capacity, China could guarantee meeting its coal demand without importing coal.

- Crude oil: limited by domestic resource, China has fully used its production capacity to produce crude oil. The output has remained around 200 million tons annually for many years. The gap between oil demand and domestic production has been increasing for years. As a result, the dependence on imported oil grew continuously, rising from 42% in 2005 to 68% in 2016. China only keeps a small amount crude oil exports active for trade purposes. Figure 3-3shows crude oil production, consumption, and imports from 2005 through 2016.

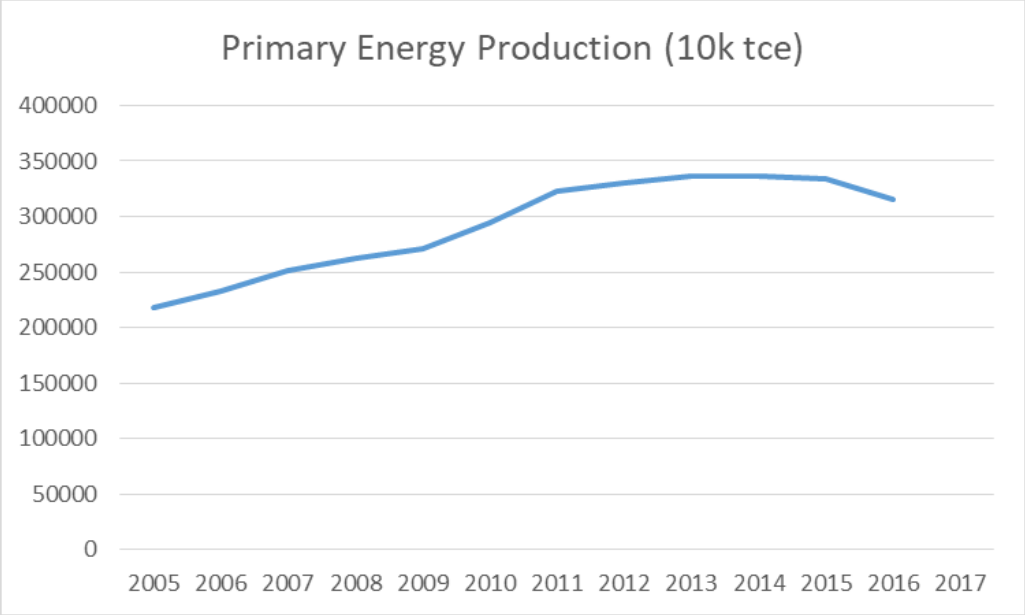

Figure 3-1: Primary Energy Production (2005-2016)

Source: China Energy Statistical Yearbook 2017

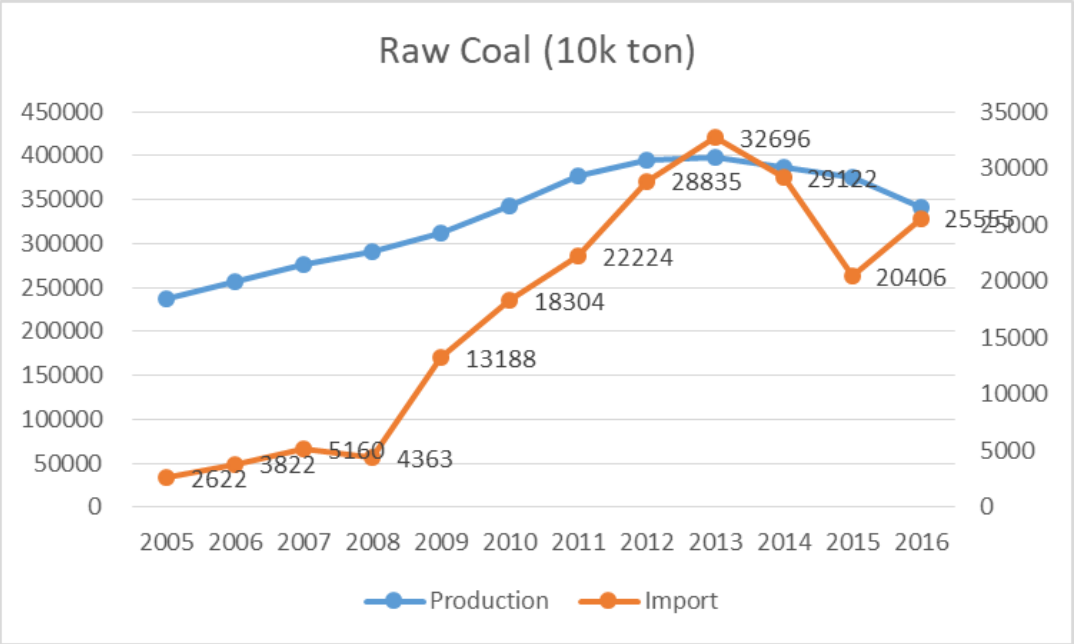

Figure 3-2: Production and Imports of Raw Coal (2005-2016)

Source: China Energy Statistical Yearbook 2017

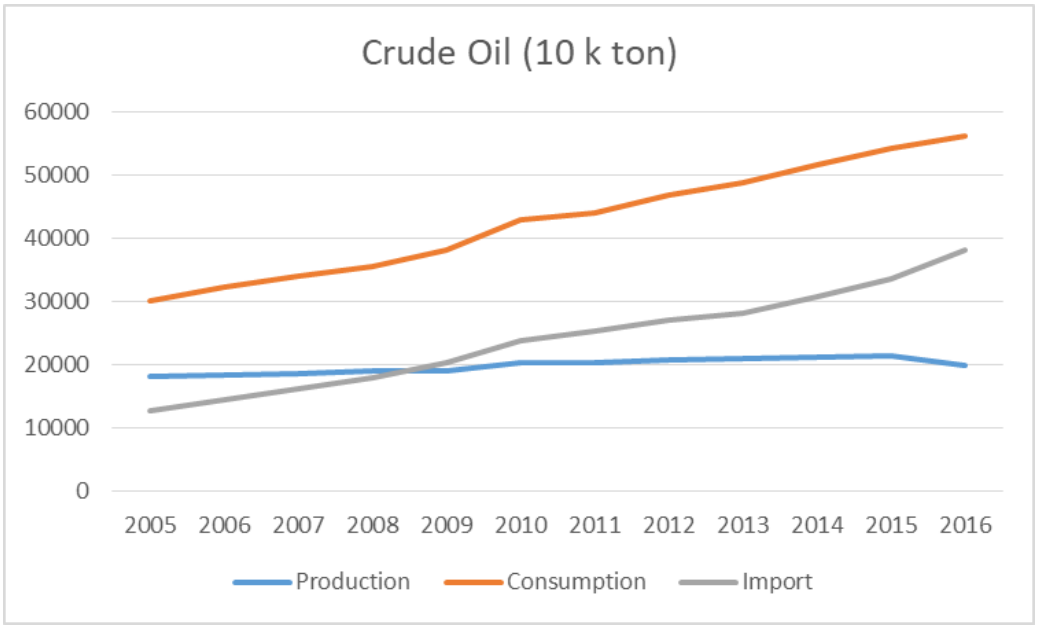

Figure 3-3: Crude Oil Production, Consumption and Imports (2005-2016)

Source: China Energy Statistical Yearbook 2017

- Natural Gas: for improving air quality of cities, China encourages switching from coal to natural gas and electricity at the point of final consumption. Large amounts of natural gas

were imported to meeting the fast growth in demand, even though domestic natural gas output increased significantly. China started importing natural gas (as liquefied natural gas, or LNG) in 2006, with total imports of 950 million cubic meters in that year. Imports were 74560 million cubic meters in 2016, having increased 77 times within ten years, while domestic production only doubled, as shown in Figure 3-4. China's import dependency for natural gas increased from zero in 2005 to 40% in 2017.

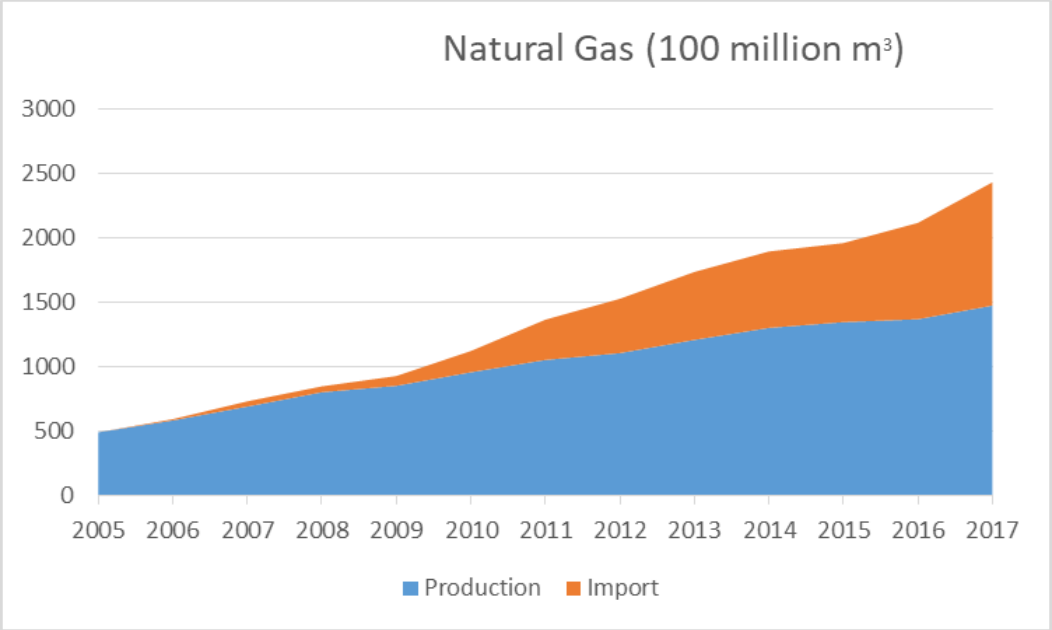

Figure 3-4: Production and Imports of Natural Gas (2005-2017)

Source: China Energy Statistical Yearbook 2017, http://www.chyxx.com/industry/201805/643374.html
2018 年中国天然气进出口统计及产量、消费量分析预测

- Primary Electricity: including hydro, nuclear, wind and solar power for electricity generation. From the point of view for reducing air pollution and GHG emissions, primary electricity is considered as a clean resource. The share of primary electricity in total primary energy production increased from 3.0% in 2005 to 5.7% in 2016. The generation from these sources was 1709.86 TWh in 2016, growing from 446.71 TWh in 2005. The details of electricity industry will be presented in Chapter 4 of this report.

By the end of 2016, China has 360 oil refinery enterprises with the total capacity of 750 million tons, ranking fourth in the world. A surplus of refining capacity has been the case for years. A certain amount of refinery products has typically been exported in order to balancing crude oil imports, and the refined products that can be made from domestic and imported oil, with domestic demand for the various refined products and for fuels used in refinery facilities operation. Figure 3-5 shows the net export and consumption of gasoline, kerosene and diesel in 2016. About one fourth of the total kerosene output from Chinese refineries was exported. The share of exports in total output was less 10% both for gasoline and diesel.

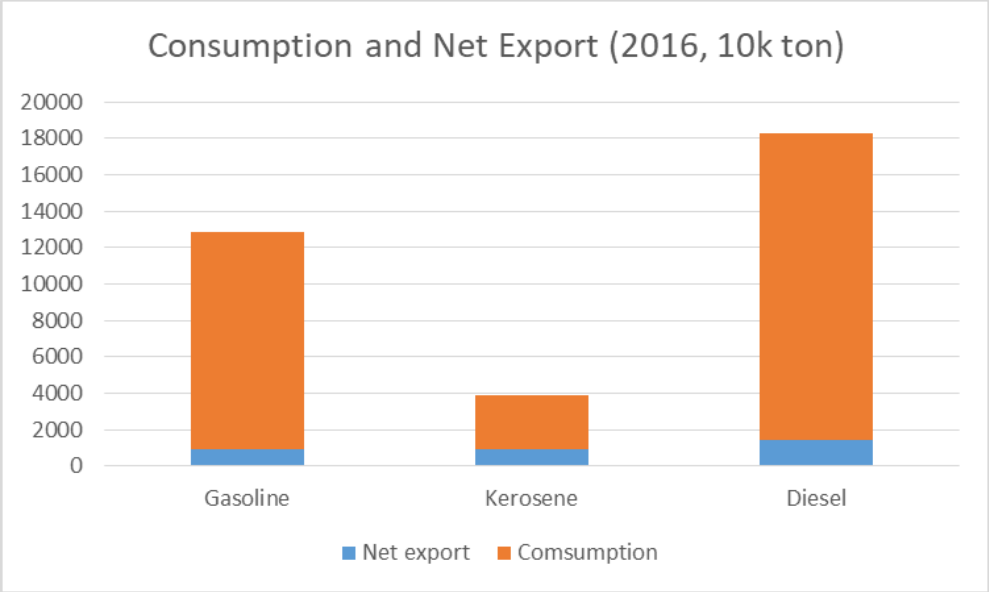

Figure 3-5: Consumption vs Export of Gasoline, Kerosene and Diesel

Source: China Energy Statistical Yearbook 2017

Crude oil imported by China is mainly shipped via very large crude carriers with tonnage in the 200,000 to 300,000 range. China has 15 ports with total berths accommodating crude oil carriers of up to 9.44 million total tons. China also has four trans-boundary oil pipelines with total transport capacity of 70 million tons per year. Table 3-1 presents the details of oil import facilities.

Table 3-1: Crude Oil Import Facilities

Crude Oil Imports Receiving Terminals					
Port	Berth (k ton)	Port	Berth (k ton)	Port	Berth (k ton)
Ningbo	1550	Huizhou	900	Qingdao	1100
Dalian	1200	Zhoushan	1450	Tianjin	400
Quanzhou	400	Zhanjiang	600	Rizhao	700
Yinkou	300	Jingzhou	250	Tangshan	300
Maoming	250	Qingzhou	100	Yangpu	300
Cross Border Oil Pipelines					
Starting Point	Destination in China	Capacity (million tons/yr)	Starting Point	Destination in China	Capacity (million tons/yr)
Kazakhstan	Xinjiang	20	Burma	Chongqing	20
Russia	Heilongjiang	15	Russia (2)	Heilongjiang	15

Source: https://wenku.baidu.com/view/6346b0dccd22bcd126fff705cc17552707225eae.html 中国主要原油码头一览; http://www.sohu.com/a/256477809_100066674 陆路进口原油管道

Since the very first LNG terminal in China was built in 2006, there have been 16 LNG terminals commissioned with a total capacity of 46.7 million tons per year. The details of the year commissioned, location, and capacity for these terminals are listed in Table 3-2. More terminals are under construction and in the planning phase. Besides these terminals, China has pipelines that connect to Central Asia, Russia and Burma (Myanmar), which transport natural gas to Xinjiang, Heilongjiang and Yunnan respectively.

Table 3-2: List of LNG Terminals

Commissioned Year	Terminal Location	Capacity (Mton/year)	Commissioned Year	Terminal Location	Capacity (Mton/year)
2006	Guangdong	6.8	2008	Shanghai	0.5
2009	Shanghai	3.0	2011	Guangdong	1.2
2013	Guangdong	3.5	2014	Hainan	2.0
2014	Hainan	0.6	2014	Shandong	6.0
2016	Guangxi	3.0	2017	Guangdong	2.0
2008	Fujian	5.2	2012	Zhejiang	3.0
2013	Hebei	6.5	2013	Tianjin	2.2
2017	Jiangsu	0.6	2018	Tianjin	0.6

Source: http://www.360doc.com/content/18/0409/13/53922645_744160804.shtml

4 Electricity Supply in China

Based on data from the China Electricity Council, China consumed 6844.9 TWh (terawatt-hours) of electricity in 2018. This level of consumption is supported by a huge domestic power industry. The total installed capacity of electricity generation was 1899.67 GW as of 2018, representing an increase of more than two-fold from 2005 levels, as shown in Figure 4-1. Meanwhile, the fuel structure for power generation has changed significantly although coal-fired thermal power still dominates the sector. Figure 4-2 and Figure 4-3 indicate the growth of electricity generation and changes in fuel sources. The share of non-fossil sources for power generation increased only 1.5 percentage point from 2005 to 2010. The share of non-fossil sources, however, reached nearly 30% in 2018, growing from 20% in 2010. Generation from wind and solar power increased significantly.

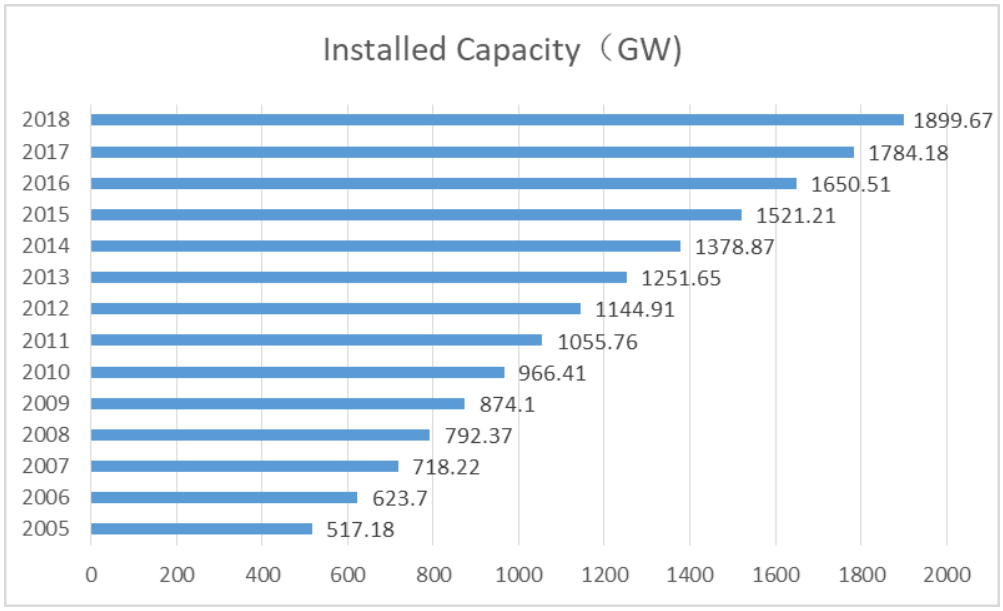

Figure 4-1: Installed Capacity of Electricity Generation

Source: China Electric Power Yearbook

http://www.cec.org.cn (China Electricity Council)

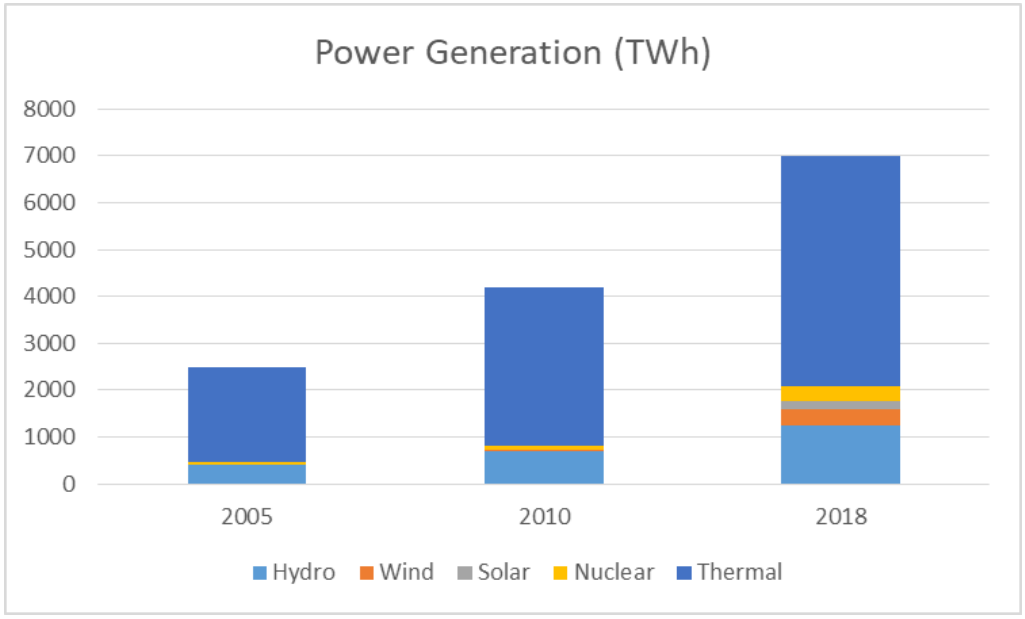

Figure 4-2: Growth of Power Generation

Source: same as Figure 4-1

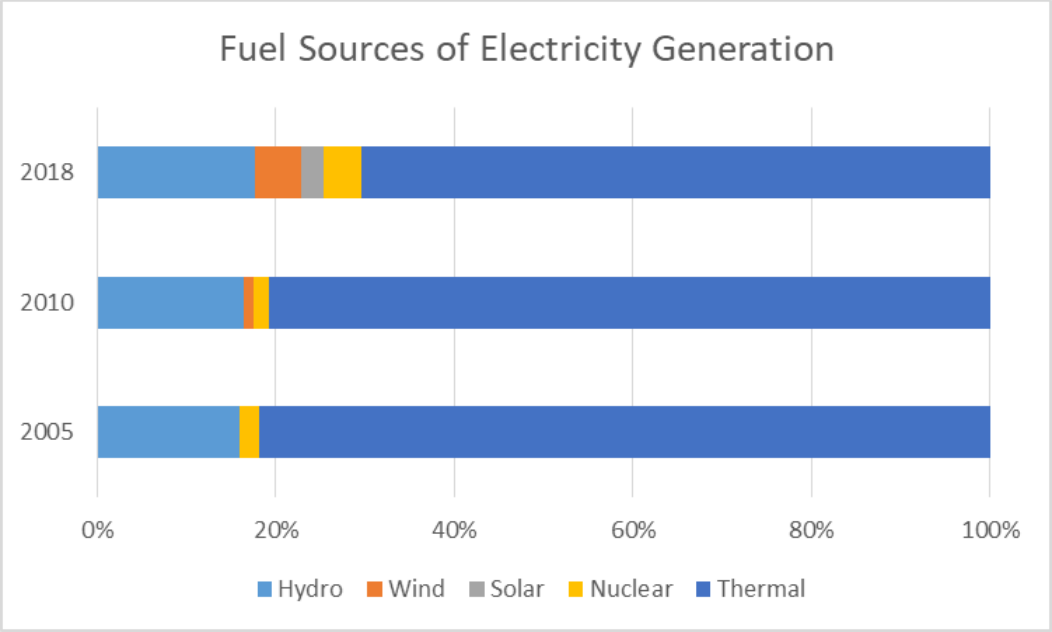

Figure 4-3: Fuel Sources of Electricity Generation

Source: same as Figure 4-1

Eleven state-owned enterprises dominate the power sector, and accounted for 60% of the total installed capacity, including 59% of thermal plants, 54% of hydro, 100% of nuclear, and 73% of wind plants. Many coal producers, with the advantage of cheap coal being available to them, are also involved in the power generation business. Large industrial consumers, mainly from the aluminum, refinery and steel sectors, have built many on-site power plants; these on-sited plants accounted for 8.6% of total installed capacity as of the end of 2016, as shown in Figure 4-4. As the reform of power sector continues, IPPs (Independent Power Producers) could play a large role in the electricity market in the future.

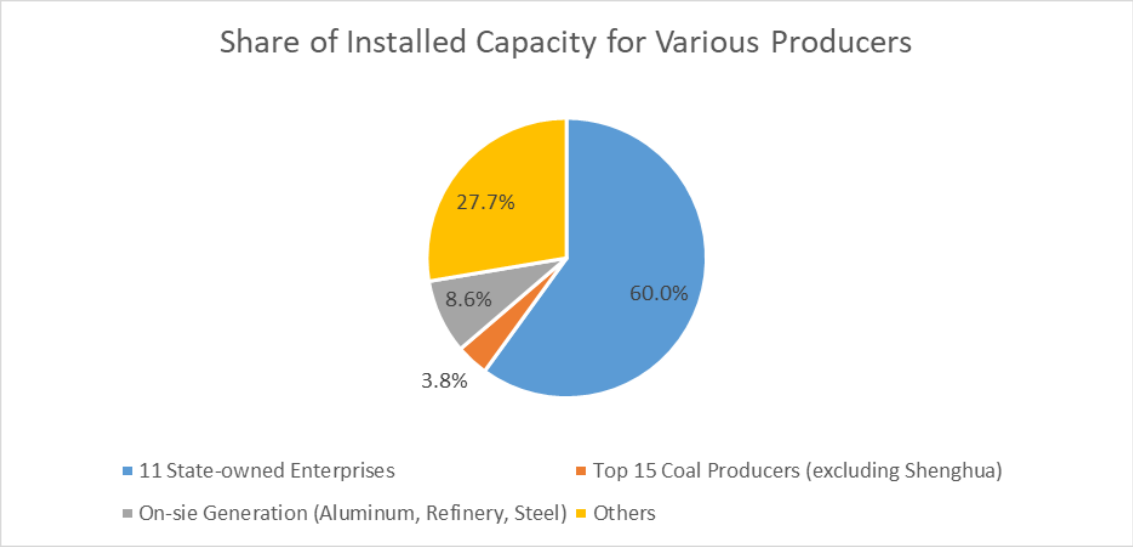

Figure 4-4: Share of Installed Capacity of Power Generation by Various Types of Producers

Source: https://www.sohu.com/a/166810996_806315

An unbalanced spatial distribution of energy resources and energy demand is a main feature of China's energy industry. Table 4-1 presents the regional grid load situation in 2014 and 2017. Large electricity transmission facilities are needed to deliver energy from one region to another. Figure 4-5 shows the ratio of generation to consumption of electricity in 2016 for each province. Most provinces needed to either import or export power from or to other regions. The five regions highlighted in Figure 4-5 are close to other countries in Northeast Asia. Liaoning purchased 15% of its electricity consumption from other regions. Shandong and Heilongjiang almost kept the balance of generation and consumption. Jilin and Inner Mongolia exported large amount of their power generated to other regions. By the end of 2018, China had 733,393 kilometers of transmission line (with voltages of 200 kV and above) with total utility-scale transformer capacity of 402,255 kVA (thousand volt-amperes).

Table 4-1: Power Grid Load (10MW)

Grid	2017 maximum generation capacity	2017 maximum generation and receiving capacity	2014 maximum generation capacity	2014 maximum generation and receiving capacity
Nationwide	**92877**	**92599**	**79729**	**79512**
Dispatched by national center directly.	4729			
North China	21354	21846	18495	19207
East China	23835	27523	19734	22074
Central China	14124	13713	18069	15053
Northeast	6386	6121	5721	5462
Northwest	9963	8148	8106	7147
Southern (Southwest)	7834	5425	13306	13614
Southern (South)	15975	16297		

Source: http://www.cec.org.cn (China Electricity Council)

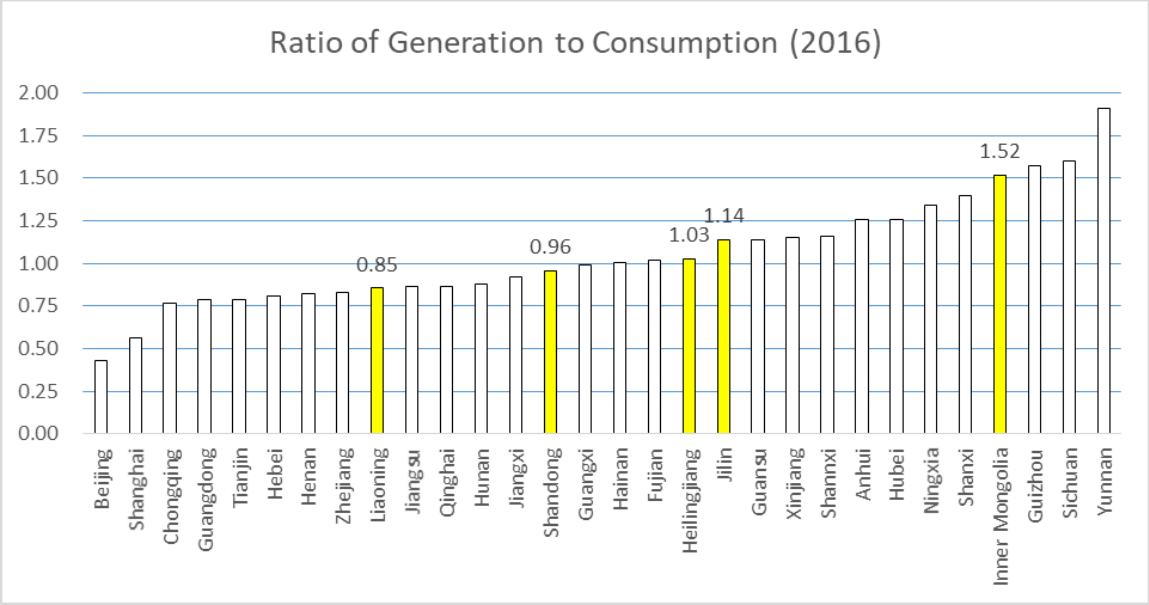

Figure 4-5: Ratio of generation to consumption of electricity in 2016

Source: China Energy Statistical Yearbook 2017

There are two grid companies, the State Grid (SG) and the Southern Power Grid. The State Grid includes 5 regional grids, which are the Northeast Grid, the North China Grid, the East China Grid, the Northwest Grid and the Central China Grid. The structure of the power transmission

sector is shown in Figure 4-6 and the structure of regional grid connections in China is shown in Figure 4-7. China has formed a nationwide grid, but the regional grids can operate individually when needed.

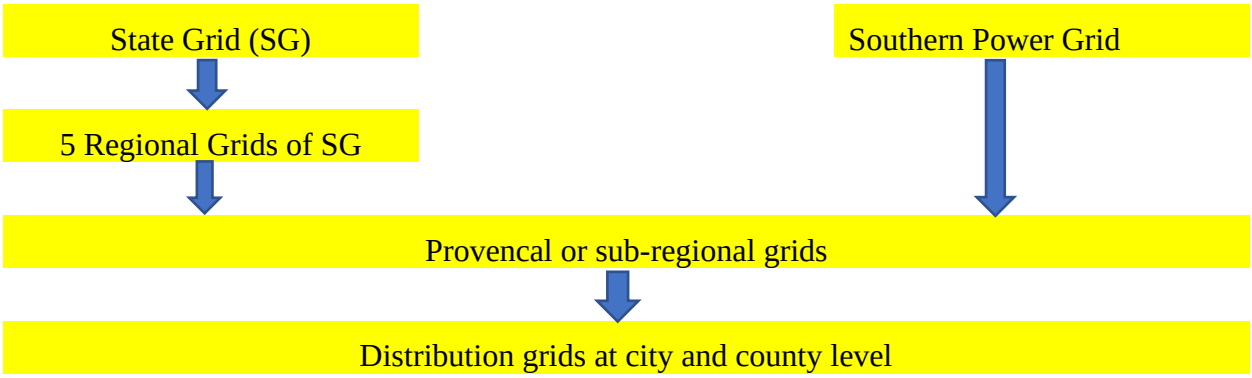

Figure 4-6: Structure of Power Grid

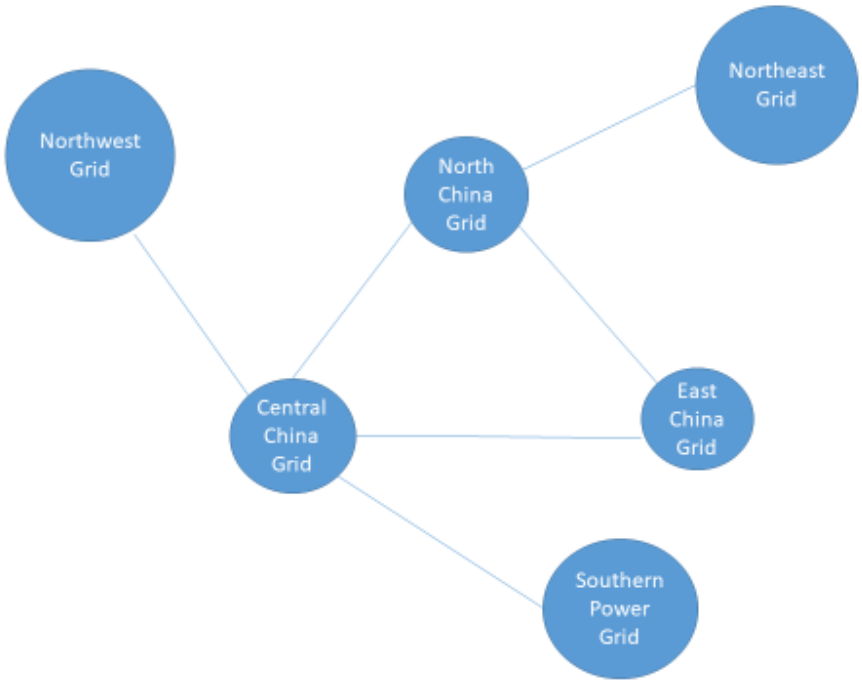

Figure 4-7: Connection of Regional Grids

Take the Northeast Grid as an example. The Northeast Grid has three parts, the north grid the covers Heilongjiang Province and Hulun Buir in Inner Mongolia; the central gird that covers Jilin Province and Tongliao in Inner Mongolia; and the south grid that covers Liaoning Province

and Chifeng in Inner Mongolia. The Northeast Grid connects to the North China Grid through its south grid.

Incorporating increasing amounts of wind, solar and hydro resources for power generation has proven to be a problem, in that full utilization of renewable resources has been difficult due to the transmission capacity limitations and the existing grid dispatch schemes. The grid companies have invested heavily in recent years to build new transmission lines and to expand the transmission capacity of existing lines. In the past two years, there have been more than forty thousand kilometers of transmission lines commissioned each year, which allowed considerable improvement in the capacity factors of hydropower, solar and wind power. The national average full-capacity hours for hydropower, solar and wind power increased to 3613, 1115 and 2095 hours in 2018, which were 16, 37 and 146 hours higher, respectively, than levels in 2017. But increasing the use of solar for power generation in the western region is still an issue. For example, Xinjiang could have supplied 2.14 TWh more solar power to the grid in 2018 than it was able to, due to transmission restrictions, which accounted for 16% of its total generation from solar PV. Gansu has a similar situation.

The capacity factors of thermal power plants have declined for years due to a surplus of installed capacity and increases in peak demand relative to baseload. More and more coal-fired power plants originally designed for baseload operation are being retrofitted for load-following operation. Although China has adopted TOU (time of use) tariffs in many regions, the load difference between peak and off-peak is continuing to increase. Other measures to reduce peak demand, such as DSM (demand-side management) and distributed energy system construction, have been implemented, but with limited impact thus far.

5 Energy Projections and Energy Policy

The general objective of China's energy policy is to support achieving long-term social and economic development targets and honor its commitments to the international community. After forty years of economic development, China has built a huge energy system and extensive energy import facilities to meet its demands for energy services. Many problems have resulted from the large scale of energy production and consumption in China. Reducing regional air pollution and CO_2 emissions are the current main forces driving changes in energy policy. These driving forces could also play important roles for years to come.

Under the influence of its "self-sufficient" principle, China has focused on using domestic resource for many years. Huge investments in increasing coal production capacity and developing and employing high-efficiency coal-fired power generation technologies were designed to make full use of domestic coal resources and minimize environmental impacts from coal combustion simultaneously. Coal liquefaction technology is considered one of the key strategic measures to reduce China's oil imports dependence. Heavy reliance on coal, however, has brought serious air pollution and high GHG emissions. Current energy policies encourage energy transitions to a clean and low-carbon energy system, as summarized below.

Energy efficiency policy

- Set targets for progressive reductions in the energy intensity of GDP, and allocate specific targets to each province;
- Set up maximum energy intensities for production of energy-intensive products and minimum energy efficiencies for to appliance and new-built buildings;
- Offer tax holidays for energy service companies;
- Set fuel economy and corporate average fuel consumption limits to be met by vehicle manufacturers and importers.

Renewable energy policy

- Develop and adopt feed-in tariffs for wind power, solar power and electricity generation from other renewables. These subsidies will be reduced or removed as the costs of these technologies decrease;
- A subsidy for bio-methane is under consideration and could be implemented in the future;
- Set up a nationwide renewable energy green certificate trading scheme to realize the goals of RPS (Renewable Portfolio Standards). The green certificate trading scheme is designed to replace feed-in tariff arrangements in the future.

Emission reduction policy

- Set maximum emissions restrictions for power plants, industrial boilers and various automobiles;
- Develop and operate a carbon market;
- Set up coal-free zones to reduce coal consumption for cooking and heating;
- Provide subsidies to residents who use electricity or natural gas for space heating in individual households.

International cooperation policy

- Encourage power companies to become involved in the construction and operation of power plant abroad, especially in the Belt and Road Initiative (BRI) countries;
- Assist with energy infrastructure construction in the BRI countries;
- Encourage cooperation with natural gas producing countries to secure natural gas supplies for imports to China.

Energy cooperation is one of the key components of The Belt and Road Initiative. The Chinese government issued the ”Vision and Actions on Energy Cooperation Silk Road Economic Belt and 21st-Century Maritime Silk Road” in 2017, which states that the principles of the cooperation under BRI is designed to be open and inclusive; seeking mutual benefit; following market operation; emphasizing safety and security; and green and harmonious development. Seven areas are proposed for the BRI cooperation.

1. Strengthen policy communications to support regional cooperation;
2. Reduce transition cost through development of a more convenient trade process;

3. Encourage Chinese enterprises to invest in energy projects through various investment options such as direct investment, PPP (public and private partnership), and merger and acquisition;
4. Undertake joint research on, development of, and manufacturing of energy equipment, as well as joint efforts in energy project construction;
5. Enlarge the construction of transboundary pipeline of oil and natural gas; promote transboundary power grid construction, and explore building regional power markets;
6. Realize the United Nations "Sustainable Energy for All" 2030 targets and the goals of the UNFCCC Paris Agreement on climate change;
7. Improve global energy governance to build a green and low-carbon energy system.

Many Chinese research organizations have projected future energy demand in China under various scenarios. Most of these research efforts are ongoing and use modeling tools of different kinds, ranging from simple to complicate. The results of these projections are regularly updated and adjusted to follow the real situation in China and for consistency with ongoing governmental planning. Several basic assumptions are adopted by most or all of these research efforts, such as population growth rates, GDP growth rates and structural change in GDP, emission caps, and others. The energy consumption per capita figures in developed countries are used as references. Similar future energy demand results with the consistent trends are typically produced by various research efforts. Energy demand is projected to be around 4.8 Gtce in 2020, 5.3 Gtce in 2030 and 6 Gtce in 2050. A probable demand peak will be reached between the years of 2035 to 2040 with a value in the range of 6.2-7.9 Gtce. After 2040, China may enter a 'zero growth phase' of energy consumption. The share of coal in primary energy consumption will decrease to 60% in 2020 and 49% in 2030, while non-fossil energy use will increase to 15% and 22%, respectively. When the oil demand peak is reached will be dependent on the rate of EV (electric vehicle) development and deployment. Different researchers have their own views on the future use of EV, as reflected in their different scenarios.

Domestic energy supply could meet 70% to 80% of national demand, and energy import dependence will remain at 20% to 30% during the next several decades. Reducing coal's shares both in demand and supply is a long-term trend. Crude oil production could remain around 230 million tons until 2030.

A new version of medium- and long-term energy development planning guidelines is under development by the Chinese government at present, since the last version only covers the years of 2004 to 2020. All research programs on future energy trends in China will be updated based on the new government documents providing those guidelines, when they are published.

6 China's Involvement in Discussions on Regional Energy Sharing

China has several bilateral physical energy infrastructure connections with other countries in the region, including as power connections with Mongolia and the DPRK, and oil and natural gas

pipeline connections with Russia. Further possibilities for regional energy sharing are under discussion by the Chinese government and Chinese companies.

6.1 Electricity

China is very active in promoting the building of global grid interconnections. Dominated by China, an international organization called Global Energy Interconnection Development and Cooperation Organization (GEIDCO) was set up in 2016. The purpose of GEIDCO is to promote the establishment of a global energy interconnection (GEI) system that can meet future global demand for electricity in a clean and green way.

The Northeast Asia Power Grid is a key component of GEI. With the support of the interconnected grid, the customers in the region could use more green power from Russia Far East region (hydropower) and Mongolia (solar PV and wind). Several projects are planned[7] including:

- Yunfeng (Jilin Province) 500 kV back-to-back project to deliver electricity from Northeast China to the DPRK;
- Mongolia-Tianjin ±660 kV DC transmission line to deliver electricity from Mongolia to North China;
- Liaoning-Pyongyang-Seoul ±500 kV three-terminal flexible DC line to support electricity demand growth in the ROK and DPRK;
- Weihai (Shandong Province)-Incheon, Goseung-Matsue ±500 kV DC transmission line to deliver clean energy to Japan to meet short-term demand; and
- Sakhalin-Hokkaido ±500 kV DC transmission line to deliver clean energy from the Russian Far East region to Japan.

6.2 Natural Gas

It has been estimated that most or all of the global growth in demand for natural gas in the next 10 to 15 years will come from the Northeast Asia region. To build a regional natural gas market and interconnection network is a common objective indicated by the countries in the region. The NAGPF (Northeast Asian Natural Gas and Pipeline Forum) was held twice in recent years, in 2015 and 2018 respectively. At these meetings, the challenges and barriers for sharing of LNG facilities in the region were discussed. Most imported LNG long-term contract pricing from Australia, Qatar, Indonesia and Malaysia is adjusted based on changes in with Brent crude oil prices. Each contract price is negotiated bilaterally and through the exchange of confidential information about the gas supply businesses. This pricing mechanism results in the natural gas purchase costs in the region being higher than other regions in the world, especially when crude oil prices are high. The region would like to set up a new pricing mechanism that could respond to the supply and demand situation more flexibly and operate similarly to market-indexed pricing

[7] Source: Northeast Asia Energy Interconnection, GEIDCO, October, 2018. https://www.igeewa.com/chanye/2018/23637.html

as in North American markets. An interconnected gas network could deal with gas demand variation better and benefit the construction of regional gas markets.

Currently, China focuses on securing gas supply and promotes regional market construction. So far, no sharing of LNG facilities is under consideration or discussion.

6.3 Oil, Oil Processing, and Oil Storage

China started to set up a national strategic oil reserve in 2004 and has a fifteen-year construction plan for its reserves. Through 2020, China will build 625 million barrels of storage capacity (about 85 million tons), which is equal to the amount of oil and oil products required to meet 90 days of net oil imports, and thus reach the level of the basic requirements of the IEA (International Energy Agency) oil stockpiling guidelines.

China has sufficient surplus oil refinery capacity for many years, with over 100 million tons per year of spare capacity as of 2018. China could more fully utilize its refinery capacity to process more crude oil and export more oil products if needed. The net export of oil products (gasoline, kerosene and diesel) reached 316 million tons in 2016, which was about 10% of China's consumption, as shown in Figure 6-1. The ratio of exports to consumption for kerosene is about 1:3, much higher than it for other oil products.

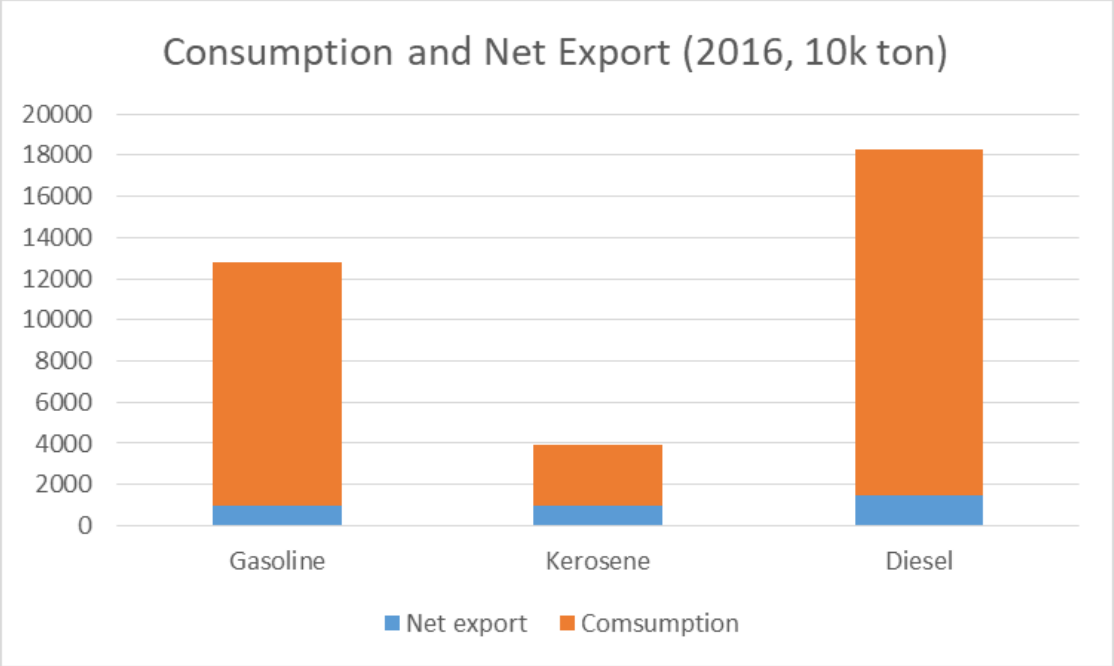

Figure 6-1: Oil Products Export and Consumption in 2016

Source: China Energy Statistical Yearbook 2017

6.4 Energy Efficiency and Renewable Energy

China has gained a great deal of experience with energy efficiency improvement and renewable energy development from its past practices, and is willing to share these experiences with other countries. China is testing various energy storage technologies for generating more electricity from renewables, although it hasn't found and commercialized a cost-effective solution so far. But China has enough production capacity for solar PV panels and wind power gen-set manufacturing to support both its rapid domestic growth in solar PV power and wind power deployment and generation, as well as to export generators to other countries. The Chinese government has emphasized that market-based cooperation must play a main role in the field of energy efficiency and renewable energy cooperation. In other words, most cooperation projects must be cost-effective and financially sustainable.

7 Report on Development/Update of the China LEAP Model

7.1 Draft Overall Structure

The base year of the China LEAP model was initially 2000 when the model was developed in an earlier project, but will be updated to 2005 in the current version of the model based on the data currently available, with historical data from statistical sources used for the years 2005 through 2017. The target (end) year for the analysis, previously 2030, will be updated to 2050. The dataset for this version of the model is being established on AES2010 (Asian Energy Security project, 2010, Draft version. We have calibrated the historical data in the model through 2017 using available source data. Most data come from the *China Statistical Yearbook*. The model structure (Figure 7-1) covers all of the sectors of the Chinese economy, and most sectors are divided into sub-sector in instances where data were readily available. Energy-intensive sub-sectors in particular are a focus.

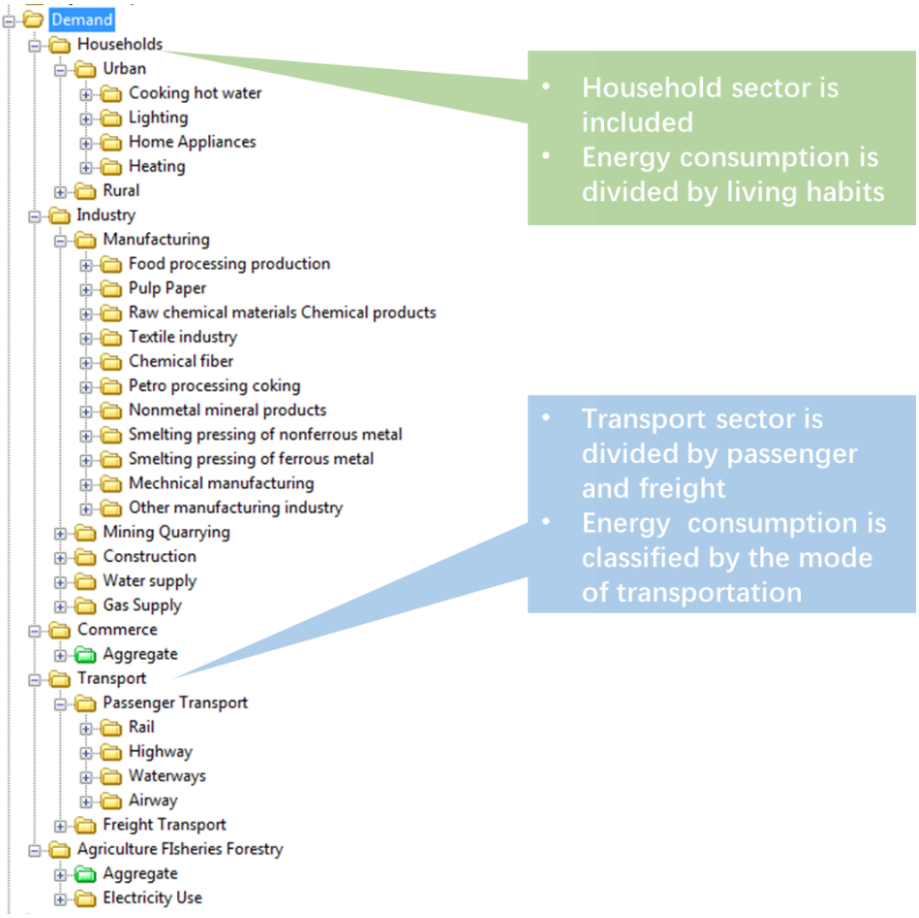

Figure 7-1: Model Structure

7.2 Key Sources of Data for New Base Year

GDP is the key driving data for future projections in the China Working Group's LEAP model. We assume that the GDP in 2050 is 6.5 times 2005 levels—although with absolute growth in real terms of slightly more than 50 percent from 2020 through 2050 as growth slows, as shown in Figure 7-2--and that the Chinese economy at that point accounts for 30% of the world economic output. With the "new normal" and the economy's ongoing structural shift, China will seek a high-quality path economic development in the coming decades.

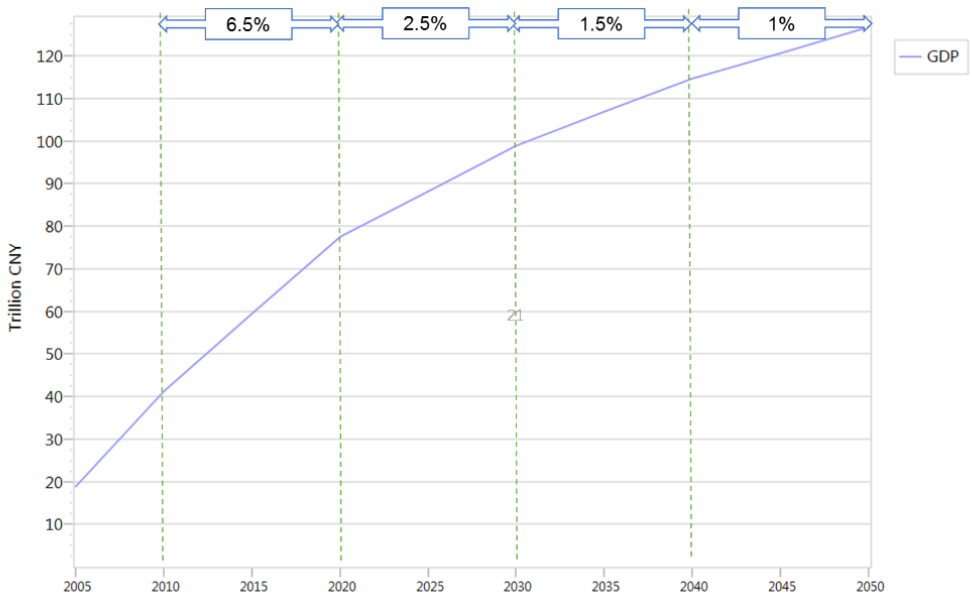

Figure 7-2: GDP Growth Assumptions

Although there is a new policy making it easier for families to have a second child in China, it is expected that this policy will not increase the population as much as expected. Estimates are that the peak for population for China will be 2028, at which time the total population will be less than 1.5 billion (see Figure 7-3). The per capita GDP will have increased by a factor of eight, relative to 2005, by 2050, with most of that growth occurring before 2020.

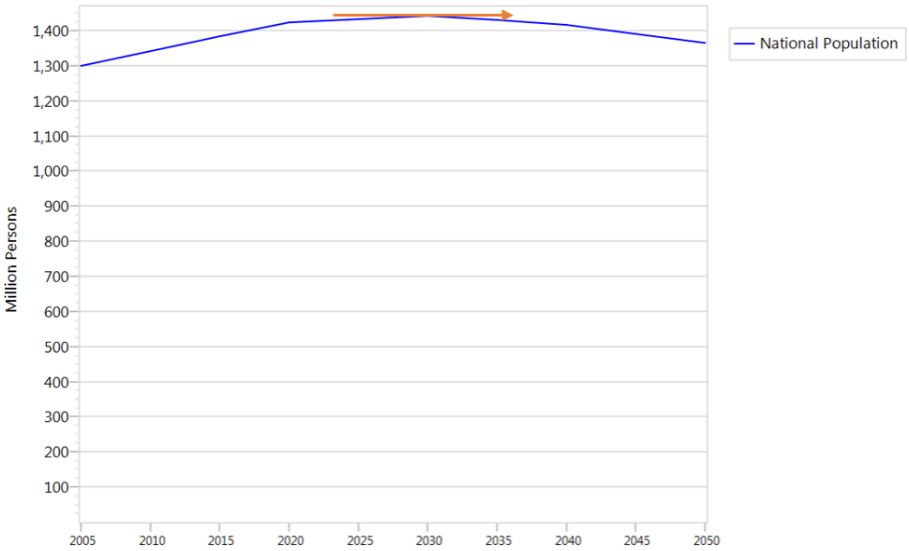

Figure 7-3: Population Assumptions

Recent changes in the economic and emissions situation in China have showed that a shift to a less energy-intensive economy will be a key factor in continuing to reduce emissions. Emissions during the period of the 12th Five-year plan have grown more slowly than in previous years. It is expected that technological improvement will still play a key role in producing emission reductions, but the economic development mode will provide the most significant contributions to emission reduction, as indicated in Figure 7-4.

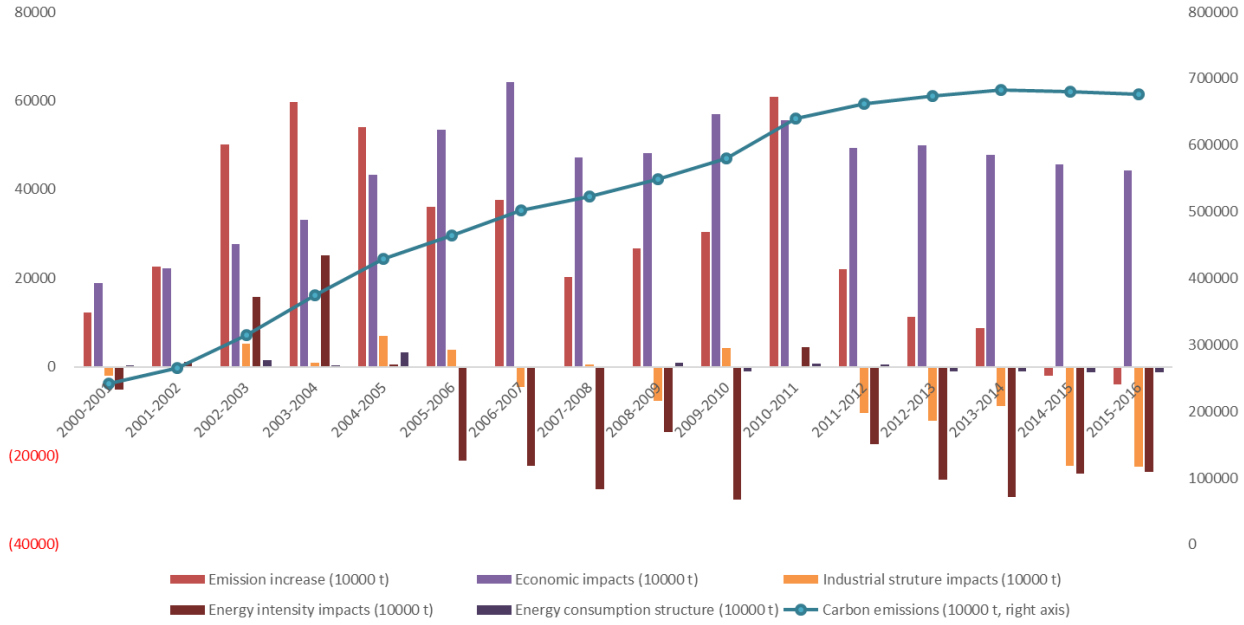

Figure 7-4: Current Economy and Emissions Situation in China

The structure of energy consumption in China has been improving in recent years, and coal consumption has decreased to 60.4% of total primary energy. Renewable Energy has developed quickly during the 12th Five Year Plan, and the growth rate of energy consumption decreased during the period of the 12th Plan compared with the 11th (see Figure 7-5). The decrease in growth in energy use is largely due to the economy's ongoing structural shift and to the coal use control policy in China.

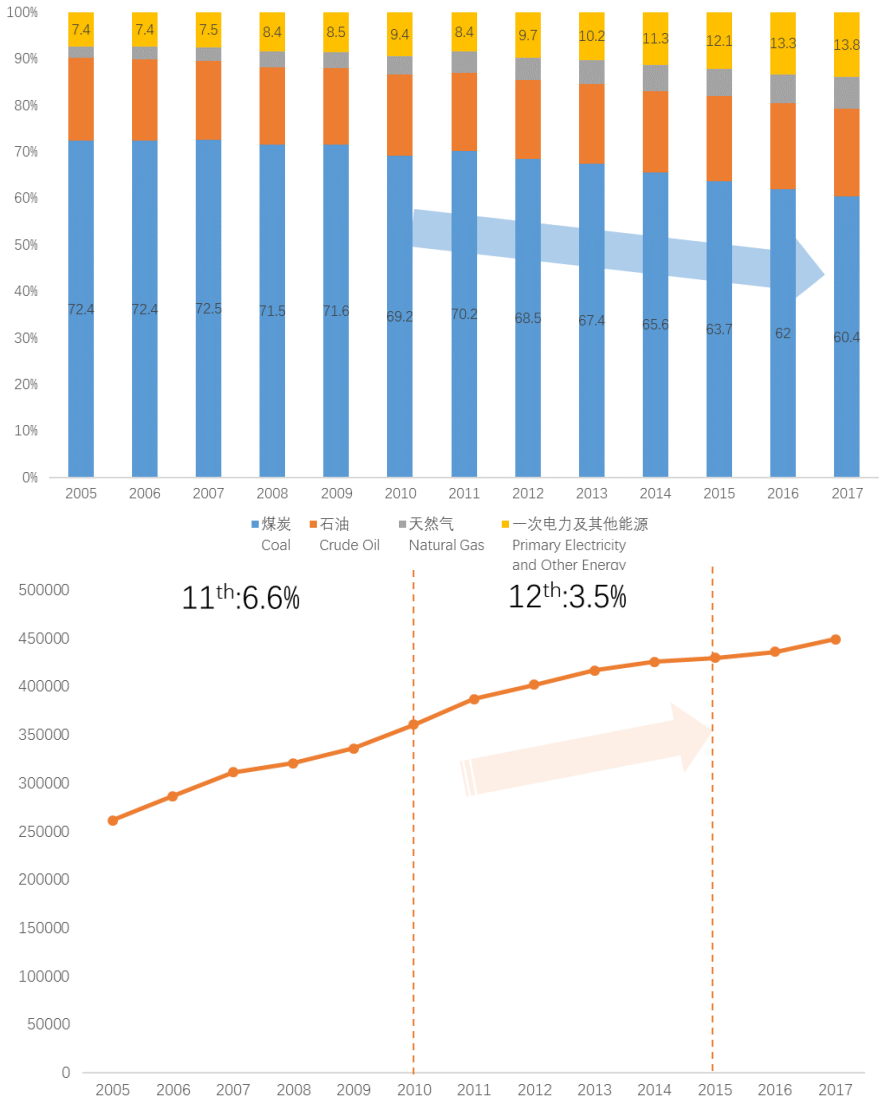

Figure 7-5: Energy Consumption in China from the 11th to 12th Five-year Plan Periods

Industry remains the biggest energy consumer in China, and accounts for 67% of national energy consumption. Manufacturing, in turn, has an 80% share of the total energy consumption of the industrial sector. The main sub-sectors, covering five energy intensive subsectors (cement, steel, raw chemistry and chemical products, petroleum, and coking), accounts for 77% of current industrial energy use. In our model other industrial subsectors will be merged. The activity levels of the main sub-sectors are shown in Figure 7-6.

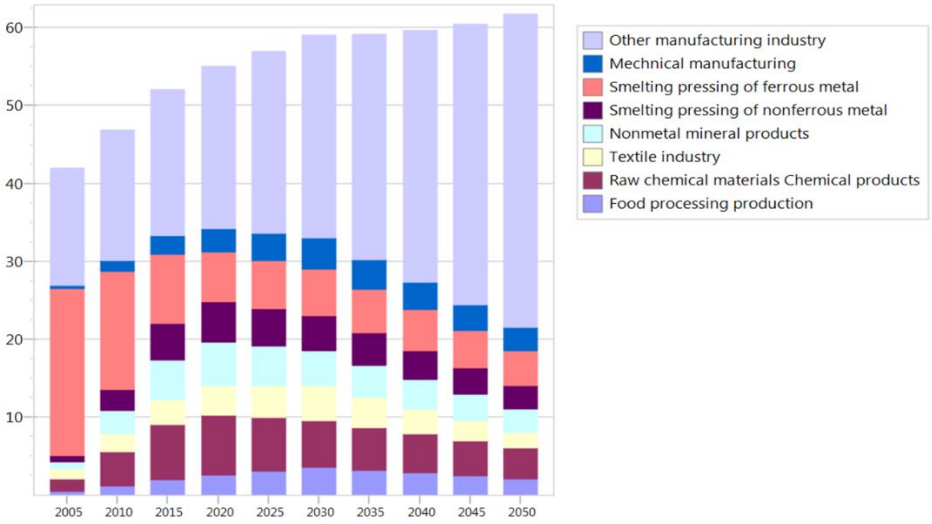

Figure 7-6: Manufacturing: Activity Level (Trillion Chinese Yuan Renminbi)

Per capita electricity consumption in 2050 in our model is in the range of 7000-10000 kWh. Electricity consumption in China will not peak before 2050 as electrification of end-uses continues. The estimated share of electricity in end uses in the major sectors by 2050 are as follows: industry 50%, transportation 25% and commercial 25%. Figure 7-7 shows recent electricity use per capita in China and in other nations and regions.

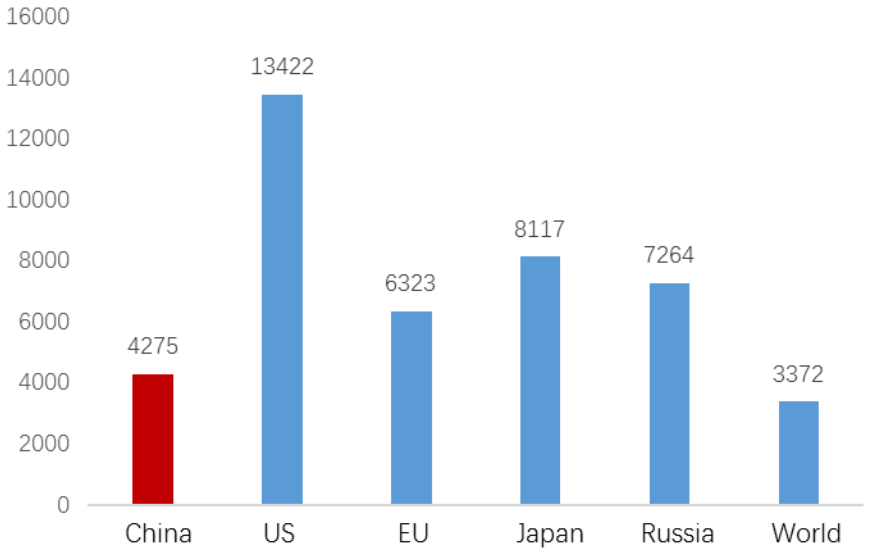

Figure 7-7: Per Capita Electricity Generation in 2016 in Different Nations and Regions (kWh)

7.3 Proposed Energy Pathways [LEAP Scenarios]

We propose three scenarios for our LEAP model of China, Coal use will decrease and as it does, there will be a large potential for control of the air pollution and other impacts of coal use, as

well as for and CO_2 emissions reduction. And the use of renewable energy is required to increase to 70%-85% of total capacity by 2050 under a scenario where global warming is limited to 1.5 degrees through climate mitigation measures. The implementation of nuclear power is expected to be flexible depending policy options in the future, as shown in the three nuclear capacity expansion scenarios shown in Figure 7-8.[8]

BAU	unit	2005	2010	2015	2020	2030	2040	2050
total capacity	GW	516.19	966.41	1525.27	1751	2304	2997	3770
Coal		391.3	682.58	939.51	920	900	880	850
Gas			26.42	66.03	100	150	200	250
Nuclear		6.84	10.82	27.17	70	130	200	300
hydro		117	216	319.54	330	410	450	500
wind		1.05	29.57	130.75	210	450	650	900
solar			0.25	42.18	110	250	600	950
other			0.77	0.09	11	14	17	20

Min	unit	2005	2010	2015	2020	2030	2040	2050
total capacity	GW	516.19	966.41	1525.27	1759	2304	3017	4240
Coal		391.3	682.58	939.51	910	880	850	820
Gas			26.42	66.03	100	150	200	250
Nuclear		6.84	10.82	27.17	88	150	250	400
hydro		117	216	319.54	330	410	450	500
wind		1.05	29.57	130.75	210	450	650	1100
solar			0.25	42.18	110	250	600	1150
other			0.77	0.09	11	14	17	20

Max	unit	2005	2010	2015	2020	2030	2040	2050
total capacity	GW	516.19	966.41	1525.27	1761	2474	3197	4690
Coal		391.3	682.58	939.51	900	850	800	720
Gas			26.42	66.03	100	150	200	250
Nuclear		6.84	10.82	27.17	100	200	350	550
hydro		117	216	319.54	330	410	450	500
wind		1.05	29.57	130.75	210	550	700	1300
solar			0.25	42.18	110	300	680	1350
other			0.77	0.09	11	14	17	20

Figure 7-8: Examples of Nuclear Capacity Expansion Scenarios

The transportation sector in our model is divided between passenger and freight transport, as well as by mode of transportation in each case. The main driving forces for the transport sector are the GDP growth rate for freight and per capita GDP for passenger transport.

Our basic assumptions for the BAU scenario focus on increasing efficiency, use of more low carbon energy sources, electrification, and intelligent design of infrastructure and energy systems. The main targets are:

- 2020: The total primary energy consumption is controlled at 5 billion tce (tonnes of coal equivalent), non-fossil energy accounts for 15% of the total, and energy consumption per unit of GDP is 15% lower than that of 2015.

[8] Capacity figures based on the main conclusions from a roadmap for China's evolution of energy production and consumption to 2050 prepared by the Energy Research Institute. Note that there remains considerable uncertainty regarding the patterns of future electricity generation in China, and as a result it is expected that the capacity trends shown here will be revised significantly in the next step of analysis by the RES China Working Group.

- 2030: The total primary energy consumption is controlled at 6 billion tce, non-fossil energy accounts for 20%, natural gas accounts for 15%, and energy consumption per unit of GDP is reduced by 50% compared with 2015.
- 2050: The total energy consumption is basically stable, and non-fossil energy accounts for more than half.

There are many existing emissions projections for the future prepared by other researchers. These projections exhibit huge difference depending on the scenario assumptions used (see Figure 7-9).

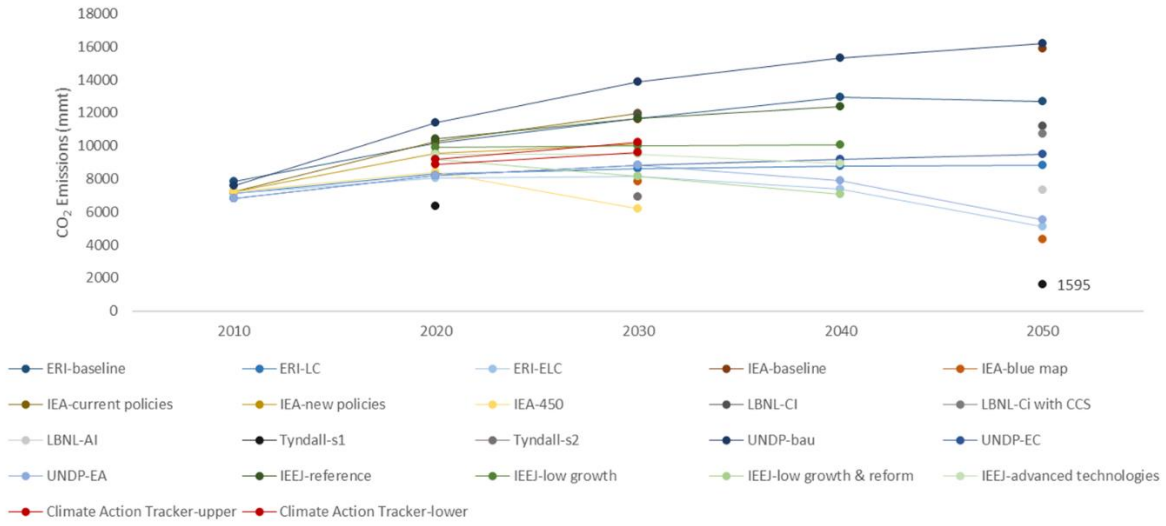

Figure 7-9: Future Emission Projections for China by Various Research Groups

8 Conclusions

8.1 Key Energy Issues for China

China plans to keep its GDP growth at a reasonable level for the coming decades. How to meet the nation's energy needs for economic and social development while using cleaner energy is the most important issue for China. China would like to improve local air quality and contribute to global GHG emissions reduction, replacing coal by using cleaner fuels, especially using more natural gas as an important option to be adopted. Meanwhile the fast growth in natural gas imports raises a further concern regarding energy security, since China's oil import dependence is quite high already. China is making great efforts to build friendly relationships with neighboring countries and oil/natural gas supplying countries.

8.2 China Approach to Regional Energy Sharing

As an important part of the current international cooperation field, energy cooperation is increasingly a focus of the countries in Northeast Asia. In the Northeast Asia region, there are energy exporting countries such as Russia and Mongolia, as well as nations with high energy demand such as China, Japan, South Korea and the DPRK.

The development of energy cooperation between Russia and China, Japan and South Korea has already happened to some extent. Increasing the scale of energy cooperation is the focus of current regional energy cooperation efforts.

8.3 Key Issues and Constraints in Regional Energy Sharing from China's Perspective

Implementing power connections will be easier than implementing other proposed cooperation modes. There are also many activities ongoing to promote power interconnections:

- On 2016/10/26, the countries of the Northeast Asia Power Network signed a cooperation memorandum;
- In 2016, the potential economic and environmental benefits from connecting power grids (opportunities and challenges) were identified, as well as the huge initial investments required, and issues associated with uncertainty of future fuel prices began to be discussed in the context of the Northeast Asia Power Network; and
- On 2018/11/1, the Northeast Asia Regional Power Interconnection and Cooperation Forum (electricity trade) group was formed.

There is ongoing research regarding electric power grid interconnections in Northeast Asia, and international groups have been organized to discuss the opportunities and challenges. The final results shown in all grid interconnection scenarios indicate that economic benefits in the form of total cost reductions depend mainly on the fuel cost saved by shifting to cheaper fossil fuel or to renewables. Achieving these economic benefits and distributing them fairly among cooperation partners are likely to be a major challenge to implementing grid interconnection.

8.4 Next Steps in China Energy Analysis

The working group will use our updated LEAP model to analyze China energy further with the consideration of GHG emissions reduction, regional energy sharing, and possible new energy policies to be issued in the near future.

8.5 Next Steps in Analysis of Regional Energy Sharing Possibilities from China's Point of View

Regional energy sharing is a team effort that requires the involvement from all countries in the region. China is very active in encouraging international cooperation not only in the region but also globally, and any response and cooperation from other countries is welcome.

III. NAUTILUS INVITES YOUR RESPONSE

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