China Energy Outlook

Understanding China's Energy and Emissions Trends

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For the past 20 years, Energy Foundation China (EFC) has provided funding to Lawrence Berkeley National Laboratory in support of data gathering and analysis, policy analysis, and development and application of the China 2050 Demand Resources Energy Analysis Model (DREAM). This report relies heavily on much of the work that EFC has funded over this period of time.

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List of Acronyms

Acronym	Meaning
AC	air conditioner
AI	artificial intelligence
AQSIQ	General Administration of Quality Supervision, Inspection and Quarantine
BATs	best available technologies
BNEF	Bloomberg New Energy Finance
BPs	best practices
BRI	Belt and Road Initiative
Btce	billion tons of coal equivalent
C	Celsius
CABEE	China Association of Building Energy Efficiency
CAFÉ	corporate average fuel efficiency
CCEEE	China Council for an Energy Efficiency Economy
CECA	China Energy Conservation Association
CHP	combined heat and power
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
CNC	computer numerical control
CNCP	China National Petroleum Corporation
CNG	compressed natural gas
CNREC	China National Renewable Energy Center
CREA	China Renewable Energy Outlook
DE	distributed energy
EEAP	Energy Efficiency Action Plan
EFC	Energy Foundation China
EI	energy intensity
ET	Evolving Transition
ETS	emissions trading scheme
EV	electric vehicle
FYP	Five-Year Plan
gce	grams of coal equivalent
GDP	gross domestic product
GHG	greenhouse gas
$GtCO_2$	gigatons CO_2
GW	gigawatt
GWP	global warming potential
HFC	hydrofluorocarbon
ICE	internal combustion engine
IEA	International Energy Agency
IP	intellectual property
IPCC	Intergovernmental Panel on Climate Change
kgce	kilograms of coal equivalent
km	kilometers
kWh	kilowatt-hour
L	liters

LEAP	Long-range Alternatives Planning
LBNL	Lawrence Berkeley National Laboratory (Berkeley Lab)
LNG	liquified natural gas
LPG	liquified petroleum gas
m^2	square meters
MEE	Ministry of Ecology and Environment
MEPS	Minimum Energy Performance Standards
MIIT	Ministry of Industry and Information Technology
MJ	megajoules
MOF	Ministry of Finance
MOHURD	Ministry of Urban-Rural Development
MOST	Ministry of Science and Technology
mpg	miles per gallon
Mt	million tons (metric)
Mtce	million tons of coal equivalent
$MtCO_2$	million tons CO_2
Mtoe	million tons of oil equivalent
MW	megawatt
NCSC	National Center for Climate Change Strategy and International Cooperation
NDC	Nationally Determined Contribution
NDRC	National Development and Reform Commission
NEA	National Energy Administration
NECC	National Energy Conservation Center
NEV	new energy vehicle
NGOA	National Government Offices Administration
NOx	nitrogen oxides
OECD	Organization of Economic Cooperation and Development
PM	particulate matter
PSL	pledged supplementary lending
PV	photovoltaic
R&D	research and development
RMB	renminbi
SCED	security-constrained economic dispatch
SCUC	security-constrained unit commitments
SO_2	sulfur dioxide
T&D	transmission and distribution
tce	ton of coal equivalent
tkm	tonne kilometers
TWh	terrawatt hour
UNESCAP	United Nations Economic and Social Commission for Asia and the Pacific
UNIDO	United Nations Industrial Development Organization
U.S.	United States
veh-km	vehicle kilometer
VOCs	volatile organic compounds
WEO	World Energy Outlook
WTO	World Trade Organization

Conversion of Primary Electricity to Standardized Energy Units

To convert primary electricity into standardized energy units, this report uses the Direct Equivalent Method unless otherwise noted, which is the same method adopted by the Intergovernmental Panel on Climate Change. This method values primary electricity at its calorific value, defined as 1 kWh = 3.6 megajoules (MJ) = 0.1229 kilograms of coal equivalent (kgce).

China uses its own method, the Power Plant Coal Consumption method, to convert primary electricity into standardized energy units based on the average amount of energy used in power plants in a specific year, treating all primary electricity as if it were generated in a thermal power plant. For the most recent year available (2017), this method values primary electricity as 1 kWh = 8.8 MJ = 0.31 kgce.

Comparisons of the different methods used to convert primary electricity into standard units are shown in the following table.

Primary Electricity Conversion Method	Power Plant Coal Consumption	Direct Equivalent	Partial Substitution	Physical Energy Content
Adopted by:	China	IPCC	U.S. EIA, BP, World Energy Council, IIASA	IEA, Eurostat, UN Statistics
Electricity source:				
Nuclear energy	Conversion to standard units based on the average heat rate (kgce/kWh) of coal fired plants in a given year. 1 kWh = 8.8 MJ = 0.31 kgce in 2017	Defined as 1 kWh = 3.6 MJ = 0.1229 kgce	Assumes 32.6% (EIA) to 38% (BP) efficiency	Assumes 33% efficiency: 1 kWh = 10.9 MJ = 0.372 kgce
Hydropower			Assumes 37% (EIA) to 38% (BP) efficiency	Assumes 100% efficiency: 1 kWh = 3.6 MJ = 0.1229 kgce
Renewable electricity (solar PV, solar thermal, and wind)			Assumes 37% (EIA) to 38% (BP) efficiency	Assumes 100% efficiency for solar PV and wind: 1 kWh = 3.6 MJ = 0.1229 kgce Assumes 33% efficiency for solar thermal: 1 kWh = 10.9 MJ = 0.372 kgce
Geothermal energy			Assumes 37% (EIA) to 38% (BP) efficiency	Assumes 10% efficiency: 1 kWh = 36 MJ = 1.229 kgce

Sources: Kraan et al., 2019; Lewis et al., 2015; UN Department of Economic and Social Affairs, Statistics Division, 2018; U.S. EIA, 2019.

Glossary of Selected Terms

Final Electricity – Electricity consumed at the point of end-use, including electricity generated from all sources, both primary and thermal (combustion). Final electricity values are converted to standard units based on the Direct Equivalent method conversion factor of 0.1229 kilogram coal equivalent (kgce)/kilowatt hour (kWh).

Primary Electricity – Includes hydroelectric, solar, wind, geothermal, and nuclear power and other sources not generated through combustion transformation. All primary electricity forms are non-fossil, but not all non-fossil electricity is primary. Biomass power generation, for example, is a combustion transformation and not a primary electricity source.

Primary Energy - Energy directly from natural resources that has not gone through any conversion processes. Non-renewable primary energy sources include crude oil, coal, and natural gas, and electricity generated from uranium. Renewable primary energy sources include biomass and electricity generated from solar, wind, tidal, and geothermal sources.

Standard Coal Equivalent - Energy use and energy savings are reported in Chinese units of standard coal equivalent (sce); values are typically expressed as metric tons of coal equivalent (tce) and million metric tons of coal equivalent (Mtce). One tce equals 29.27 gigajoules (GJs) and 27.78 million British thermal units (MBtus).

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Executive Summary

China is the world's largest consumer and producer of primary energy as well as the world's largest emitter of energy-related carbon dioxide (CO_2). China surpassed the U.S. in primary energy consumption in 2010 and in CO_2 emissions in 2006. In 2018, China was responsible for 21% of total global primary energy use (IEA, 2019a) and about 29% of global energy-related CO_2 emissions (IEA, 2019b).

China's 1.4 billion people consume energy to meet their daily needs, including heating and cooling of their living and working places, fuel for cooking their meals, electricity to power their appliances and equipment, and fuels for both their own personal transportation as well as the products they purchase.

Residential and commercial buildings have consumed roughly 20% of primary energy use for more than two decades, with building energy consumption nearly tripling since 2000. China has been rapidly building new urban residential and commercial buildings over the past two decades. Energy used to heat, cool, cook, and power appliances and equipment in residential and commercial buildings increased during this period due to China's growing middle-class, improved standard of living, and rapid urbanization.

Energy use to transport China's residents as well as raw materials (e.g. coal), manufactured products, and other goods has increased significantly, growing from consumption of 28.95 million tons of coal equivalent (Mtce) - a 5% share - in 1980 to 368.54 Mtce – a 9% share - in 2018, or 9.7% on an adjusted basis. China's electric vehicle market began to grow in 2011, gained momentum in 2014, and was further boosted in 2015 with significant government financial support. The sales of new energy vehicles (NEVs), which includes battery electric vehicles, hybrid vehicles, fuel-cell electric vehicles, hydrogen vehicles, and other new energy vehicles grew 114% per year on average from 2011 to 2018 and now account for almost 6% of China's passenger car market.

Energy is further used in China to manufacture vehicles and consumer products, along with construction materials that are used to build China's buildings, roadways, bridges, and other infrastructure. While China exports manufactured products and consumer goods, the majority of these are consumed in China to support domestic demand. China's industrial sector is not only the largest economic sector by far in terms of primary energy consumption but its share of total energy use has remained relatively constant, fluctuating between 67% and 73% since 1980 and settling at 70% from 2013 to 2018.

The energy required to meet these consumer demands is both produced domestically and imported. China is rich in domestic coal resources and coal is China's dominant fuel source, not only for production of electricity but also as a source of energy for China's vast industrial sector, which has been responsible for roughly 70% of China's primary energy consumption for decades. But use of natural gas and oil is growing rapidly, especially in the buildings and transport sectors.

Overall, China's energy structure is electrifying, growing from a share of 19% electricity in total final energy use in 2010 to 23% in 2017. The buildings sector is approaching 30% electrification – up from 25% in 2010 – followed by industry at nearly 25%, with transport at a mere 4% in 2017. While still dominated by fossil fuels, recent growth in China's electricity generation capacity has mostly been in solar, wind, hydro, and nuclear power - also to meet the growing demands of the industrial, buildings, and transport sectors. The share of non-fossil energy (renewable electricity plus nuclear) in total primary energy consumption has grown from 6.2% in 2000 to 12.3% in 2017, and it is reported to have reached 14.3% in 2018 (Liu, 2019).

These trends also mean that China is decarbonizing, with CO_2 emissions per unit of energy consumption – which held steady at a rate of about 2.5 gCO_2/gce from 1980 to 1995 and then fluctuated between 2.5 and 2.4 gCO_2/gce until 2010 – recently declining at a relatively rapid rate to the current value of 2.19 gCO_2/gce, the lowest it has been in China. China's value is still high when compared to the global average (1.63 gCO_2/gce), the U.S. (1.53 gCO_2/gce), and Europe (1.37 gCO_2/gce) (IEA, 2019c).

During China's 13th FYP period (2016-2020), energy intensity and CO_2 emission intensity reduction targets of 15% and 18%, respectively, were established for 2020 along with a goal of having approximately 15% of total primary energy from non-fossil sources. After the release of the 13th FYP, an energy development plan under the 13th FYP was announced (NDRC, 2016a). This plan established several key goals for 2020, including limiting China's total energy consumption to under 5 billion tonnes of coal equivalent (Btce) and capping the total coal consumption within 4.1 Btce by 2020. The plan also calls for increasing the share of non-fossil energy consumption to 15% and above by 2020 while reducing the share of coal in total energy use to below 58%.

China appears to be on track to meet all of its key 13th FYP 2020 energy and CO_2 emissions goals, except the services sector share of value added which was 52.2% in 2018, just slightly behind the value needed to keep on a steady pace to the goal of 56%. Regarding installed capacity for renewable electricity sources, China installed 175 GW of solar by 2018, exceeding the 2020 goal of 110 GW. China is on track to meet or exceed the hydropower capacity goal (352 GW installed; 2020 goal of 380 GW), wind power capacity goal (184 GW installed; 2020 goal of 210 GW), and the nuclear power capacity goal (45 GW installed; 2020 goals of 58 GW).

In April 2017, China released the *Energy Supply and Consumption Revolution Strategy (2016-2030)* that reiterates a number of its 2020 national energy goals and also sets additional goals for 2030 (NDRC and NEA, 2016). The new 2030 goals are to cap China's absolute primary energy consumption at or below 6,000 Mtce, increase the share of non-fossil energy in total primary energy to 20%, increase the share of natural gas in total primary energy consumption to 15%, and strive to have 50% of total power generation from non-fossil sources.

In September 2016, China ratified the *Paris Agreement* which commits participating parties to "holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels" (UN, 2018a). China's specific *Paris Agreement* commitments, as conveyed through its Nationally Determined Contributions (NDCs), include peaking CO_2 emissions around 2030 and making best efforts to peak early as well as increasing the share of non-fossil fuels in primary energy consumption to around 20% by 2030. China's 2030 NDCs also include lowering CO_2 emissions per unit of GDP by 60% to 65% from the 2005 level (UNFCCC, 2018).

China is steadily making progress on both the non-fossil share and CO_2 emissions intensity goals. In 2018, the share of non-fossil fuels in primary energy consumption – using China's power plant coal consumption conversion methodology – was 13.8%, which is on pace to reach the 2020 goal of 15%. China's energy-related CO_2 emissions per unit of GDP relative to 2005 have dropped an estimated 47% as of the end of 2018, which is on track to meet the goal of reducing CO_2 emissions intensity by 60%-65% by 2030.

As of the end of 2018, China's energy-related CO_2 emissions have continued to grow, predominately due to increased combustion of fossil fuels during the 2017 to 2018 period and are currently estimated to have just surpassed 10 $GtCO_2$, a 4% increase over the 2015 value. This recent growth in energy-related CO_2 emissions will need to peak and begin to decline in the next decade if China is going to realize a peak in CO_2 emissions by 2030 or earlier.

To achieve its myriad domestic and international energy-related goals, China has established many policies and programs at the national, subnational, and sectoral levels. Some of these are relatively new while others are continuations of long-standing efforts. Some are just now in the pilot stage while others started as pilots and are now larger efforts.

A review of 42 selected policies and programs currently in place in China focused on energy and related emissions found that China relies on a wide variety of instruments to achieve its goals, including regulatory/administrative, economic, informational, voluntary, and motivational policies and programs.

More than half of the 42 reviewed policies are predominately regulatory/administrative in nature. These 24 mandatory policies are found in all sectors and have been generally successful, although some are struggling while others are just in the pilot phase. Examples of mandatory policies include the appliance energy efficiency standards and fuel economy standards for light- and heavy-duty vehicles. To complement these mandatory approaches, China also is using voluntary components in 15 policies to encourage participation in a more flexible manner. Examples of policies with voluntary components include the low carbon pilot cities and provinces and the Energy Efficiency Top-Runner program. Fifteen policies are either predominately economic or include economic components, such as subsidies, in support of the overall programmatic goal. Examples include the national emissions trading scheme, Made in China 2025, and subsidies for New Energy Vehicles. Other strategies are also deployed including informational (18) with the goal of influencing consumer choices and motivational (11) to encourage program participation.

Looking forward to 2050, a Continuous Improvement Scenario of China's future energy outlook is developed using a detailed bottom-up energy end-use model (China 2050 DREAM) and assuming China adopts the maximum shares of today's commercially available, cost-effective energy efficiency and renewable energy supply by 2050. Under this scenario, China's primary energy consumption peaks in 2029 at 5,400 Mtce and reaches a non-fossil share of 29% in primary energy by 2050 using the direct equivalent method for conversion. By sector, primary energy use peaks by 2025 for industry, 2034 for buildings, and 2035 for transport. In the power sector, generation from renewables and other non-fossil fuels replace thermal generation when environmental merit dispatch is utilized, with non-fossil sources generating 89% of China's electricity in 2050. With energy efficiency and fuel switching (especially electrification) in the energy end use sectors and decarbonization of the power system, China's CO_2 emissions peaks in 2025 at a level of 10,930 $MtCO_2$ and declines to 5,010 $MtCO_2$ by 2050. CO_2 emissions from industry peak before 2019, around 2030 for buildings, and by 2035 for transport.

Compared to similarly defined scenarios in the latest projections by 9 other international and China-based organizations, the 2050 Continuous Improvement Scenario has a notably different shape in primary energy use trend than other projections, with plateauing in the mid-2025s, peak in 2029, and significant declines thereafter. Only two other Chinese studies project a peak in primary energy use between 2025-2030, and none of the other similar scenarios show a marked decline in energy use prior to 2050. Given similar trends in the near-term, this divergence in trend is likely due to more aggressive efficiency and fuel switching assumptions and accounting of more saturation effects in the China Energy Outlook 2050 Continuous Improvement Scenario.

In terms of energy-related CO_2 emissions, the Continuous Improvement Scenario finds a 2025 CO_2 peak year consistent with projections by two other international and a Chinese organization, but at a higher peak level. Similar to projections by two Chinese organizations, the Continuous Improvement Scenario also finds rapid decline in CO_2 emissions after 2030, but with a 2050 CO_2 level that is lower than nearly all the other studies. The Continuous Improvement Scenario's projected non-fossil shares of total power generation are very similar to two other international projections for 2025 and 2030, but 10 percentage points higher in 2040 and 2050 than other studies.

Overall, this report shows that following the 2015-2016 period when energy use and energy-related emissions were leveling off or slightly declining, China's energy consumption and CO_2 emissions are increasing again as demand grows to meet the needs of China's urbanizing consumers. China has many policies and programs in place to address this growth that rely on all sorts of approaches from mandatory to voluntary and including economic instruments, informational campaigns, and motivational tactics. Considering the varying effectiveness of these policies and programs, a scenario of continuous improvement shows that indeed, Chinese energy use and CO_2 emissions will continue to increase until 2029 and 2025, respectively.

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Introduction

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Lawrence Berkeley National Laboratory's (Berkeley Lab's) China Energy Group was founded in 1988. Since then, the China Energy Group has worked collaboratively with researchers and policymakers in China and around the world to both bring information on energy use and energy efficiency to China and to understand China's energy use and energy-related trends. This China Energy Outlook presents key information on China's historical energy and emissions trends and current energy-related policies and programs, both of which inform our future outlook regarding China's energy use and emissions to 2050.

Chapter 1 presents the most recent data available on **China's Current Energy and Emissions Trends**, covering energy consumption, energy production, and energy-related CO_2 emissions. The chapter shows that despite an earlier peak in 2014 and slight downturn in 2015 and 2016, China's energy use and related CO_2 emissions have begun to climb again. China has collected energy-related data regularly since 1980, tracking the production, transformation, import and export of different sources of energy as well as how energy has been consumed by the economy's industry, buildings, and transportation end-use sectors. Berkeley Lab's China Energy Group has published the *China Energy Databook*, a fully relational database of national and provincial energy balances, plus detailed sectoral energy end-use tables developed in Microsoft Access containing over 120,000 data points, since 1992.[1] LBNL's China Energy Group has also published an accompanying *Key China Energy Statistics* booklet with selected figures and tables

[1] For more information, see https://china.lbl.gov/china-energy-databook

from the *Databook* that summarizes key energy data.[2] The primary source for all of the energy data for those efforts as well as for this report is China's National Bureau of Statistics.

Chapter 2 presents the most recent information available on **China's Key Energy Targets, Policies, and Programs**, covering China's energy and energy-related emissions commitments in the 13th Five-Year Plan (2016-2020), the Nationally Determined Contributions to the Paris Agreement, and other documents as well as providing an update on 42 policies and programs currently in place in China focused on energy and related emissions. This chapter builds on the China Energy Group's 30+ years of policy and program development, implementation, and analysis in China and is augmented by information provided through 18 interviews with research staff and policymakers in China.

Chapter 3 presents a Continuous Improvement Scenario of **China's Future Energy Outlook** to 2050, modeling what China can achieve in terms of energy use and energy-related CO_2 emissions with adoption of the maximum shares of commercially available, cost-effective energy efficiency and renewable energy supply by 2050. This scenario is built using the China Energy Group's China 2050 Demand Resources Energy Analysis Model (DREAM) which was developed in collaboration with many international and Chinese researchers over the past 15 years.[3]

[2] For more information, see https://china.lbl.gov/publications/key-china-energy-statistics-2016

[3] For more information, see https://china.lbl.gov/dream

Chapter 1: China's Current Energy and Emissions Trends

Introduction

China is the world's largest consumer and producer of primary energy as well as the world's largest emitter of energy-related carbon dioxide (CO_2). China surpassed the U.S. in primary energy consumption in 2010 and in CO_2 emissions in 2006. In 2018, China was responsible for 21% of total global primary energy use (IEA, 2019a)[4] and about 29% of global energy-related CO_2 emissions (IEA, 2019b).

China's 1.4 billion people consume energy to meet their daily needs, including heating and cooling of their living and working places, fuel for cooking their meals, electricity to power their appliances and equipment, and fuels for both their own personal transportation as well as the products they purchase. Energy is further used in China to manufacture these consumer products, along with construction materials that are used to build China's buildings, roadways, bridges, and other infrastructure. While China exports manufactured products and consumer goods, the majority of these are consumed in China to support domestic demand.

The energy required to meet these consumer demands is both produced domestically and imported. China is rich in domestic coal resources and coal is China's dominant fuel source, not only for production of electricity but also as a source of energy for China's vast industrial sector, which has been responsible for roughly 70% of China's primary energy consumption for decades. But use of natural gas and oil is growing rapidly, especially in the buildings and transport sectors.

Overall, China's energy structure is electrifying, growing from a share of 19% electricity in total final energy use in 2010 to 23% in 2017. The buildings sector is approaching 30% electrification – up from 25% in 2010 – followed by industry at nearly 25%, with transport at a mere 4% in 2017. While still dominated by fossil fuels, recent growth in China's electricity generation capacity has mostly been in solar, wind, hydro, and nuclear power - also to meet the growing demands of the industrial, buildings, and transport sectors. The share of non-fossil energy (renewable electricity plus nuclear) in total primary energy consumption has grown from 6.2% in 2000 to 12.3% in 2017, and it is reported to have reached 14.3% in 2018 (Liu, 2019).[5]

These trends also mean that China is decarbonizing, with CO_2 emissions per unit of energy consumption – which held steady at a rate of about 2.5 gCO_2/gce from 1980 to 1995 and then fluctuated between 2.5 and 2.4 gCO_2/gce until 2010 – recently declining at a relatively rapid rate to the current value of 2.19 gCO_2/gce, the lowest it has been in China. China's value is still

[4] To calculate primary energy, electricity units need to be converted to standardized energy units. For this report, we use the direct equivalent method unless otherwise noted when we use China's power plant coal consumption method. The International Energy Agency (IEA) uses the physical energy content method. For more information on these conversion methods, see Lewis et al., 2015.

[5] This reported value of 14.3% likely reflects improvement in the rate of curtailment of wind and solar electricity generation and a 25% jump in nuclear power capacity in 2018.

high when compared to the global average (1.63 gCO_2/gce), the U.S. (1.53 gCO_2/gce), and Europe (1.37 gCO_2/gce) (IEA, 2019c).[6]

Chapter 1 of the *China Energy Outlook* provides updated information on China's energy consumption and production – mostly through 2018 – supplemented with information on 2019 trends where data are available. This chapter starts with the key drivers of China's energy use – population and urbanization – and then focuses on energy consumption trends by end-use sectors of the economy. Next, trends in the production of fuels used to meet these end-use demands are discussed, identifying recent areas of growth as well as discussing China's import dependence. Finally, the chapter concludes with a discussion of China's energy-related CO_2 emissions, showing that even though China dominates in terms of total current CO_2 emissions, its per capita CO_2 emissions are below those of the U.S., Japan, and Russia.

Population, Urbanization, and GDP Trends in the Context of Energy Use

Population growth, increased urbanization, and economic growth are all important drivers of the increases in China's energy consumption. Figure 1-1 shows the average annual growth rates of these three macroeconomic indicators for China for 1980-2019.

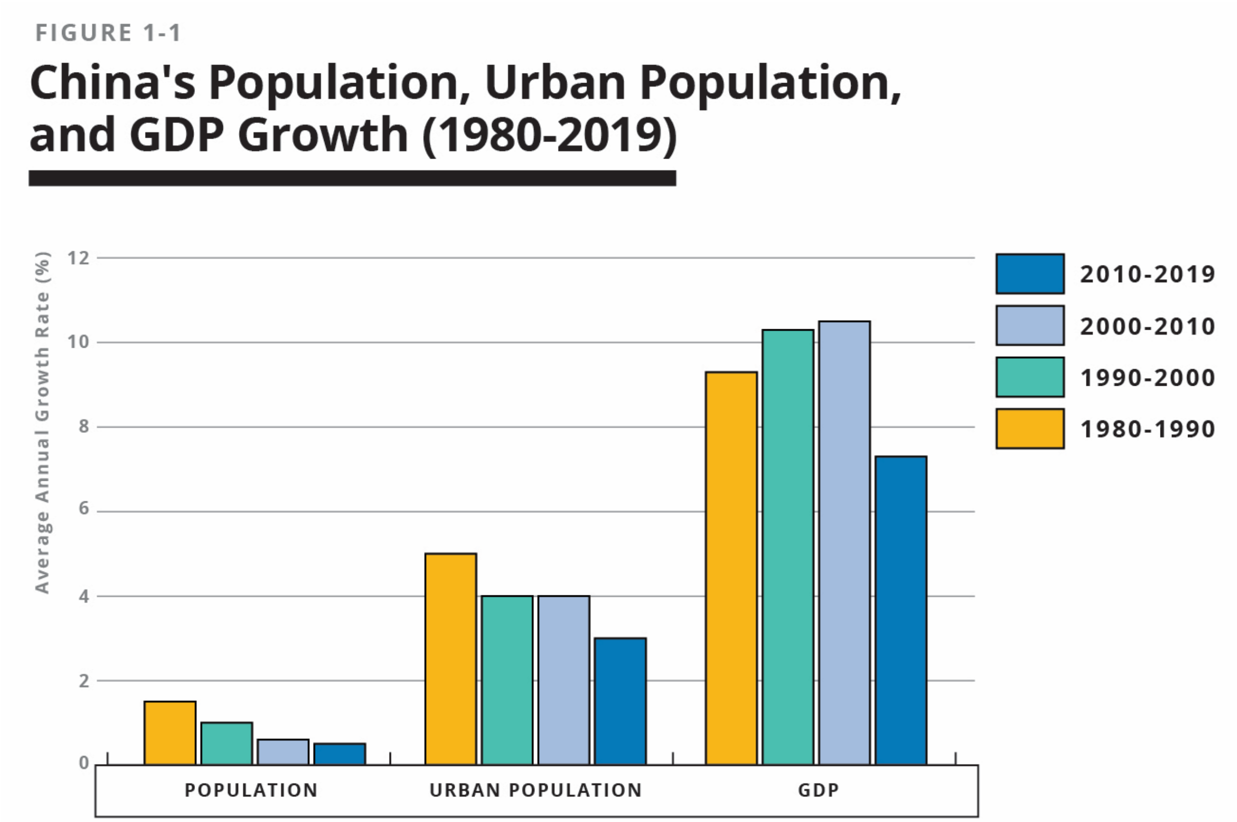


Figure 1-1. China's Total Population, Urbanization, and GDP Growth (1980-2019)
Source: NBS, various years (a).

[6] Note that the IEA calculates China's 2018 value to be 2.09 gCO_2/gce, slightly lower than the LBNL value.

Despite the relaxation of China's one-child policy effective January 1, 2016 (NPC, 2015), China's population growth has continued the slow-down that started around the turn of the century. Between 1980 and 1990, China's population grew at an average annual rate of 1.5% per year, slowing to 1.0% between 1990 and 2000, to 0.6% between 2000 and 2010, and to 0.5% between 2010 and 2019 (NBS, various years (a)). In 2019, China's population grew only 0.3% from the previous year, significantly slower than the world's annual population growth rate of 1.1% and slightly below the United States 0.5% annual population growth rate in 2019 (World Bank, 2019).

As of 2018, China is still the world's most populous country with 1.395 billion people, followed closely by India with a population of 1.353 billion, growing at 1.1% per year. The United Nations projects that India's population will surpass China's in 2027 (UN, 2019).

Around 1995, large numbers of China's rural populace began to migrate to the cities. A campaign to develop existing towns into new urban centers led to the number of cities increasing from 193 in 1978 to 672 by 2018, with 14 cities having a population of more than 5 million household registered residents (NBS, 2019a). China's urbanization rate consequently increased rapidly, reaching 54.3% (exceeding the world's average urbanization rate of 53.5%) in 2014 and approaching 61% in 2019 (Figure 1-2). However, China's urbanization rate is still significantly below the United States (82%), Japan (92%), and South Korea (81%) and is projected to reach 80% by 2050 (UN, 2018b).

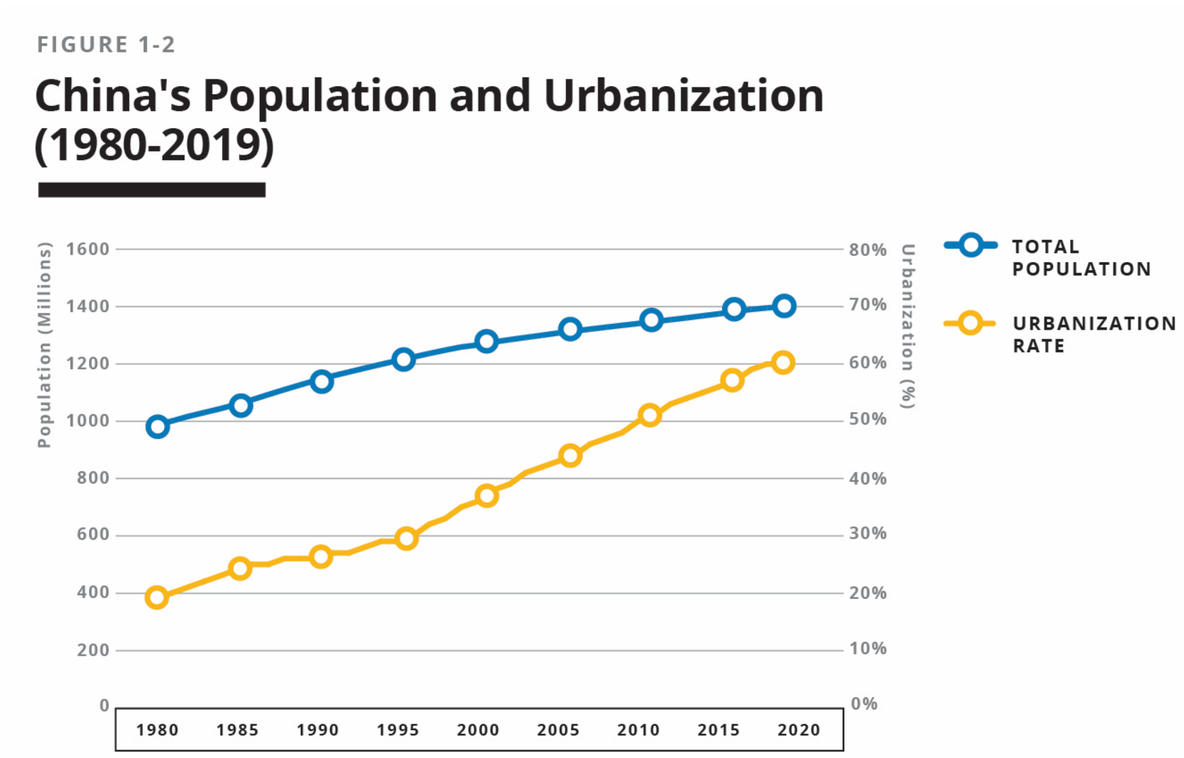


Figure 1-2. China's Population and Urbanization (1980-2019)
Source: NBS, various years (a).

China's new urban residents require accommodation, schooling, health care, appliances, transportation, food, clothing, water, sewerage, and other services, all of which take energy to produce or use. Rising income levels and demand for greater energy services and amenities of urban dwellers result in 1.4 times higher consumption of commercial (non-biomass) energy than rural residents (NBS, 2018a).[7] Urban households have much higher ownership rates for major household appliances including clothes washers, refrigerators, televisions, air conditioners, computers and microwaves than rural residents. For example, the saturation rate of air conditioners was 140 units per 100 urban households but was only about 60 units per 100 rural households in 2018 (NBS, 2019b).

China's growing urban population also accounts for an even larger share of energy and CO_2 emissions embodied in urban goods and infrastructure, which requires vast amounts of cement and other construction materials for housing, commercial buildings, highways, transportation, and related urban services. Chinese cities experienced a construction boom over the past two decades, driven in part by stimulus funding after the 2008 global financial crisis but also sustained and rapid urbanization.

China's gross domestic product (GDP) has grown at extremely variable rates since 1980. On average, GDP grew 9.5% per year from 1980 to 2018. But growth was even higher during 1982-1988 (11.8%), 1991-1996 (12.2%), and 2003-2007 (12.1%). Currently, China is experiencing a slow-down in GDP growth with values under 7% per year since 2015 and the growth rate between 2017 and 2018 was 6.6%, the lowest it has been since 1990.

Primary energy consumption per capita in China has increased more than five times since 1980 (Figure 1-3). This increased demand for energy is driven by increased income per person and increased urbanization, both of which lead to increased use of energy for heating and cooling buildings, powering appliances and other equipment, and transporting people and goods around China. Growing urbanization further leads to increased need for industrial products such a cement, steel, glass, and aluminum to build the buildings and infrastructure needed to support wealthier urban dwellers.

The rate of growth in per capita primary energy use has been different across different periods of time. The fastest growth occurred between 2002 and 2005 when energy use per capita grew an average of 13.5% per year and the economy was expanding by an average of 10% per year.

[7] When use of biomass is included, rural energy per capita is higher than urban.

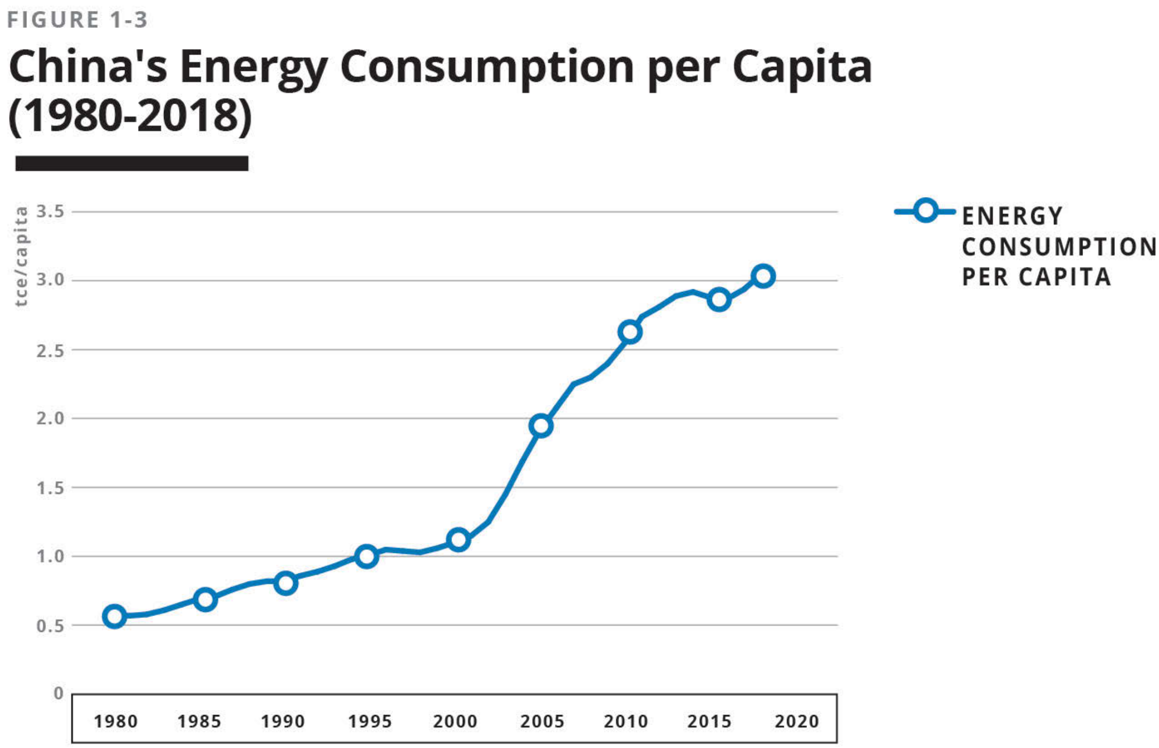


Figure 1-3. China's Total Primary Energy Consumption per Capita (1980-2018)
Source: NBS, various years (b).

Recently, with China's policies focusing on energy conservation and energy-related emissions reduction, the growth of China's energy use per capita slowed to 4% per year between 2006 and 2014. Energy use per capita decreased between 2014 and 2016, largely driven by the slowdown of the national economy that started in 2010, but began to increase again in 2017 and 2018 and reached 3.1 tce/capita in 2018.

Figure 1-4 shows that China's 2018 primary energy consumption per capita has surpassed the world average of 2.7 tce/capita. While an average Chinese person consumes more energy than people living in Africa and in Central and South America, the same average Chinese person consumes less energy than people living in the Middle East, Europe, Japan and much less than in Russia and the U.S. On average, Chinese energy consumption per capita is roughly one-third as much as energy consumption per capita in the U.S. It is expected that energy use per capita in China will continue to grow as per capita incomes and living standards improve.

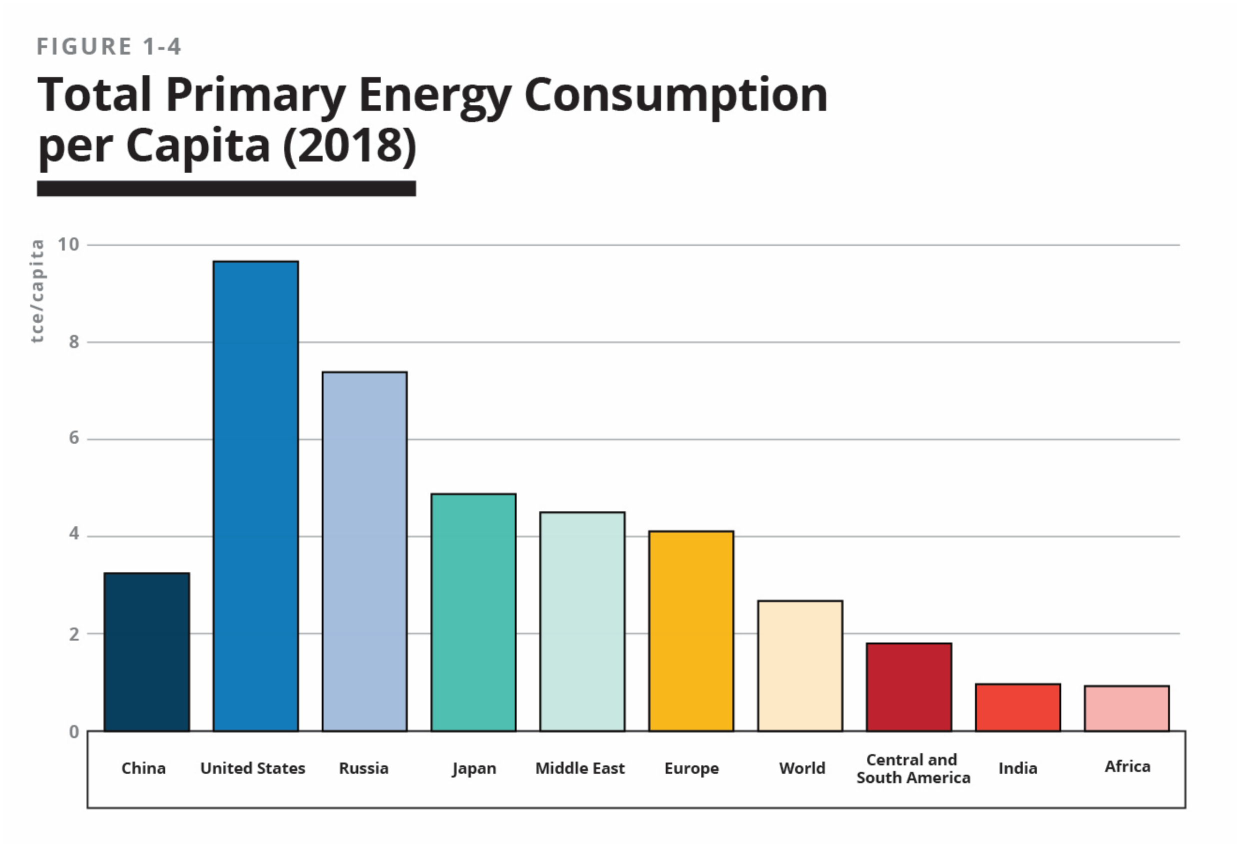


Figure 1-4. Total Primary Energy Consumption per Capita, Selected Regions and Countries (2018)
Source: IEA, 2019c. Based on WEO2019 data.
Note: Primary energy consumption here is calculated by the IEA using the physical energy content method for converting electricity to standardized energy units. Using this method, China's energy use per capita in 2018 was 3.26 tce/capita.

Similar to the trends of total energy use per capita in China, China's primary electricity consumption per capita also increased significantly over the last four decades, largely driven by improved living standards and rising incomes which led to increased demand for energy-consuming equipment such as appliances, heating, and cooling in buildings. Figure 1-5 shows that an average Chinese person already consumes more electricity than the world average. However, an average Chinese person only consumed 37% of the electricity that an average U.S. resident consumed in 2018.

FIGURE 1-5

Electricity Consumption per Capita (2018)

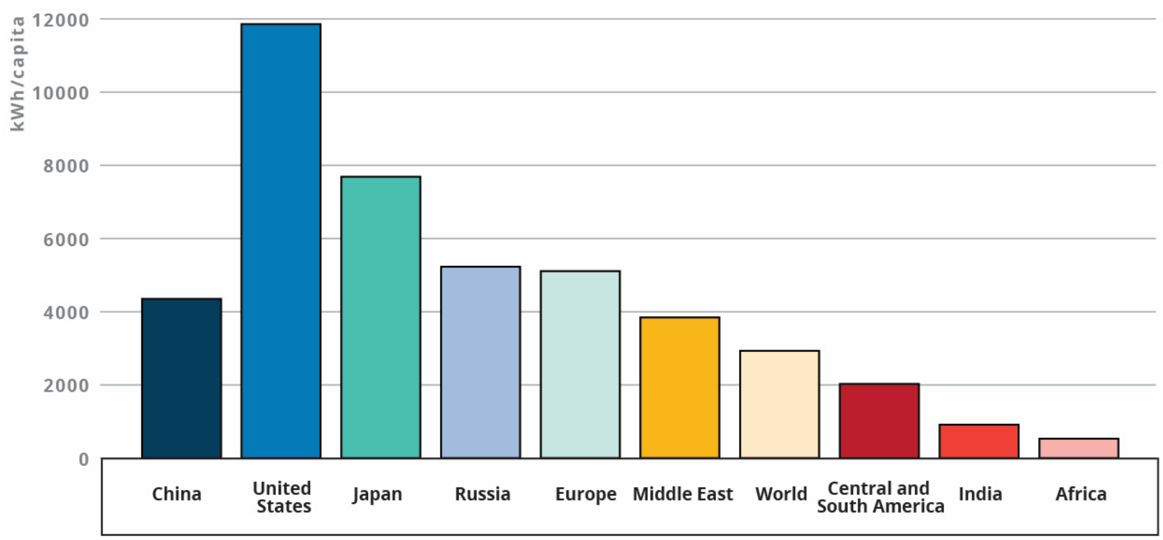


Figure 1-5. Electricity Consumption per Capita, Selected Regions and Countries (2018)
Source: IEA, 2019c. Based on WEO2019 data. All rights reserved.

China's primary energy consumption per unit of gross domestic product (GDP), also referred to as economic energy intensity, dropped on average 4.5% per year from 1980 to 2002 (Figure 1-6). Government policies and programs implemented during this period focused on strict oversight of industrial energy use, provision of financial incentives for energy-efficiency investments, provision of information and other energy-efficiency services through over 200 energy conservation service centers spread throughout China, energy-efficiency education and training, and research, development, and demonstration programs (Sinton et al., 1998; Sinton et al., 1999; Sinton and Fridley, 2000; Wang et al., 1995).

The period 2002-2005 saw a dramatic reversal of the historic relationship between energy use and GDP growth for a variety of reasons, including China's entry into the World Trade Organization (WTO), rapid urbanization, and the reduction in government attention to energy efficiency during the 1990s. As a result, energy use per unit of GDP increased an average of 4.7% per year over these three years, and total energy use grew from 1,619 Mtce to 2,508 Mtce during this period.

FIGURE 1-6

Total Primary Energy Consumption per Unit of GDP (1980-2019)

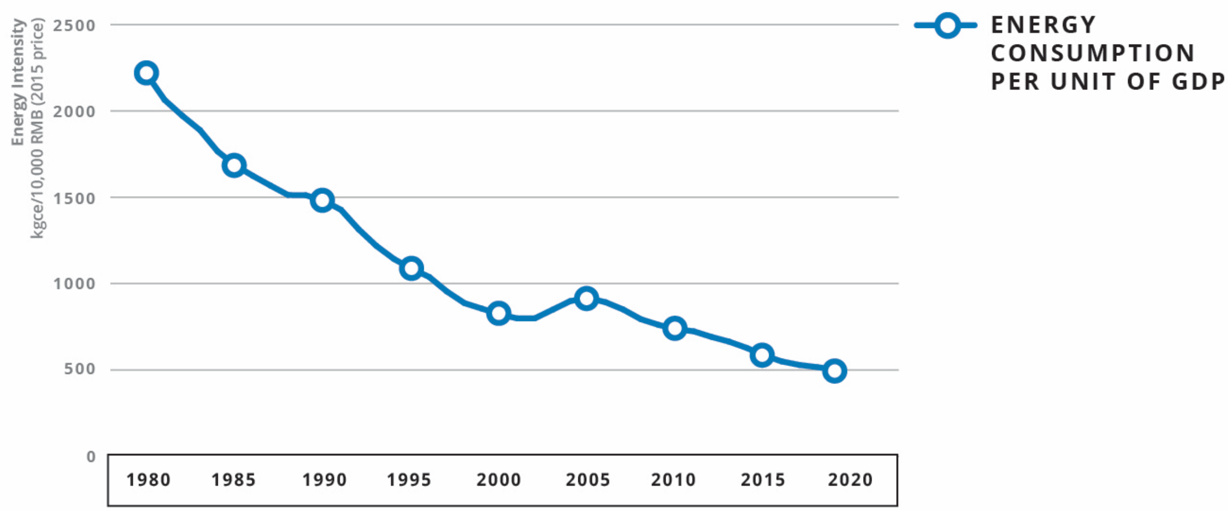


Figure 1-6. China's Primary Energy Consumption per Unit of GDP (1980-2019)
Source: NBS, various years (b).

Starting in 2006, the Chinese government established binding targets in the 11th (2016-2010), 12th (2011-2015), and 13th (2016-2020) Five-Year Plans to reduce economic energy intensity (Table 1-1) and implemented a number of policies and programs to support achievement of these targets (see Chapter 2). As a result, China was able to "basically" achieve the 11th FYP target,[8] surpass the 12th FYP target, and is on track to achieve the 13th FYP target by 2020.

From 2005 to 2018, following implementation of these policies and programs, China's economic energy intensity has once again declined annually, at an average rate of -4.4%, similar to the declines experienced during the 1980-2002 period. This decline, however, has slowed recently to -3.7% between 2016-2017 and -2.5% between 2017-2019.

Table 1-1. China's Economic Energy Intensity (Primary Energy Use per Unit of GDP) Reduction Targets

Economic Energy Intensity Reduction	11th Five-Year Plan 2006-2010	12th Five-Year Plan 2011-2015	13th Five-Year Plan 2016-2020
Target	- 20%	- 16%	- 15%
Achievement	-19.1%	-20%	-14% (as of 2019)

[8] The term "basically" was used in central government documents, such as the *Review of the Energy Conservation and Emission Reduction during the 11th Five-Year Plan*, to describe that China came very close to meeting the "around 20%" target (http://www.gov.cn/gzdt/2011-09/27/content_1957502.htm).

Energy Consumption by End-Use Sector

Primary energy consumption in China has increased continuously since 1980, at an average annual growth rate of 5.4% (Figure 1-7). There have been two notable periods when growth diverged significantly from the historical trend. First, from 2002 to 2005, growth skyrocketed to an average of 15.7% per year. Then, growth stalled following a short-lived "peaking" of total energy consumption in 2014 when use slightly surpassed the 4,000 Mtce point and then dropped in 2015. But this plateauing ended when energy consumption growth resumed again in 2016 due to economic stimulus programs. Production of many industrial commodities in China increased during the first half of 2019 compared to 2018. If these trends continue, it is likely that China's total primary energy consumption may increase in 2019, largely due to increased industrial production.

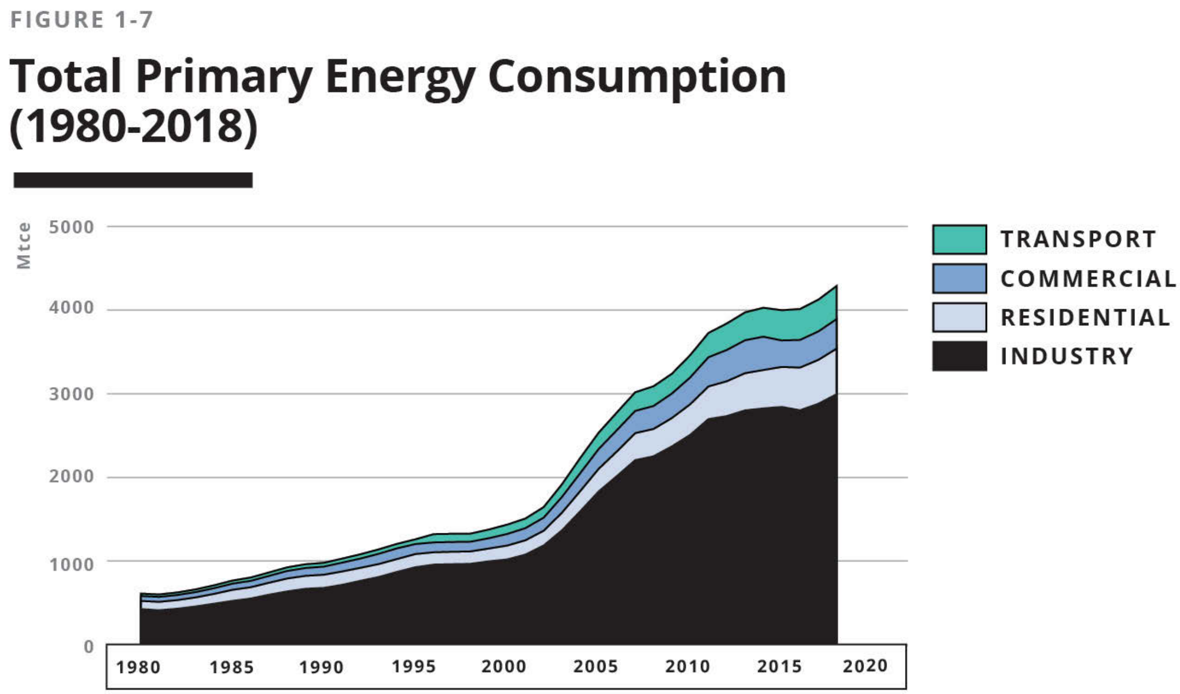
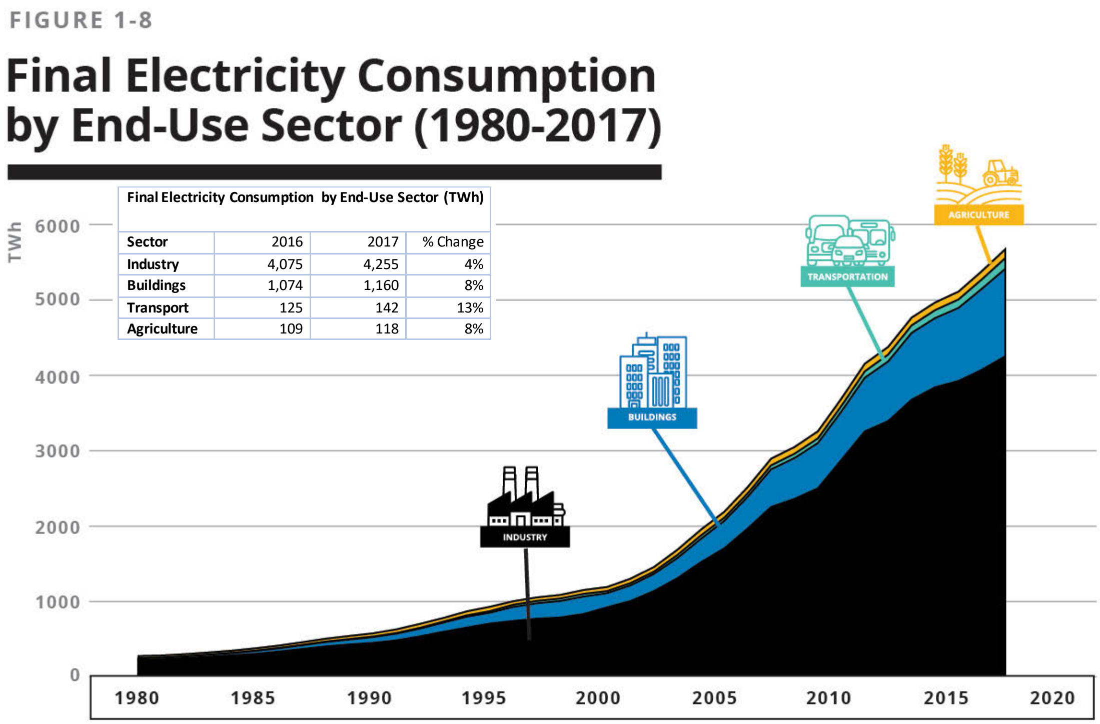


Figure 1-7. China's Primary Energy Consumption by End-Use Sector (1980-2018)

Source: NBS, various years (b).
Note: Industrial sector energy use also includes agriculture and construction. Sectoral energy use is estimated for 2018.

China's is now the world's largest consumer of primary energy, using 4263 Mtce in 2018. Around 2010, China surpassed the U.S., the world's second largest consumer of primary energy (3,644 Mtce in 2018) (U.S. EIA, 2015; U.S. EIA, 2019), and has remained the largest primary energy consumer in the world since then (BP, 2019a).

China's total final electricity consumption grew over 20 times from 1980 to 2017. The industrial sector is the largest electricity consumer in China, accounting for over 80% in 1980 and 69% in 2017. The average annual growth rate of electricity consumption in the industrial sector from 1980 to 2017 was about 8%. Electricity consumption in the buildings sector and transport sector grew faster than the industrial sector, with average annual growth rates of 13% and 15% from 1980 to 2017, respectively, reflecting the rising rate of electrification of these sectors.



Sector	2016	2017	% Change
Industry	4,075	4,255	4%
Buildings	1,074	1,160	8%
Transport	125	142	13%
Agriculture	109	118	8%

Figure 1-8. China's Final Electricity Consumption by End-Use Sector (1980-2017)
Source: NBS, various years (b).
Note: Construction sector is included in the industrial sector.

The share of electricity in final energy use has increased from 15% in 2000 to 19% in 2010 to 23% in 2017 (Figure 1-9). Among the end-use sectors, the electrification rate in the transport sector is the lowest, at 4% in 2017. The buildings sector has the highest electrification rate, reaching almost 30% in 2017, followed by the industrial sector with an electrification rate of 24%. The electrification rate decreased slightly from 22% to 21% in the agriculture sector during the same period.

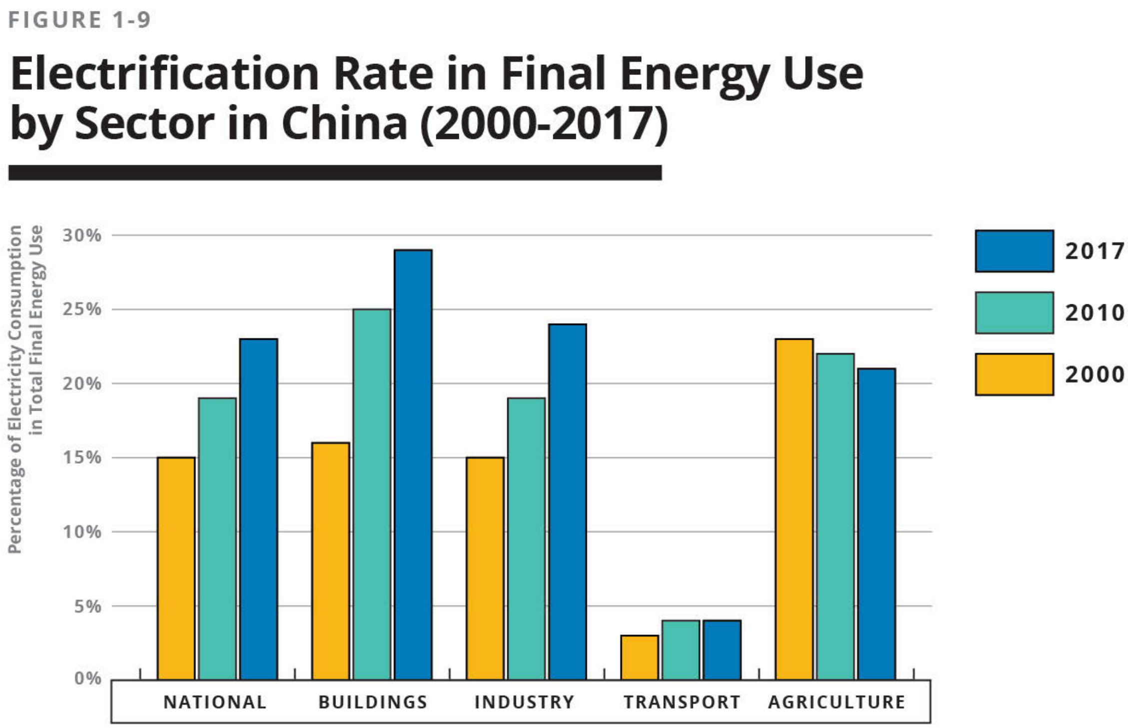


Figure 1-9. Share of Electricity Consumption in Total Final Energy Use (2000, 2010, and 2017)
Source: NBS, various years (b).
Notes: 1) Industry data also includes construction sector; 2) final energy use includes transportation consumption in end-use sectors, e.g., buildings and industrial sector, according to China's statistical methodology.

Buildings Sector

The residential and commercial buildings sector[9] is currently responsible for consumption of about 13% and 8%, respectively, of China's total primary energy. Buildings have been a roughly 20% share of primary energy use for more than two decades, with buildings energy consumption nearly tripling since 2000.

Key drivers of energy use in the buildings sector include urbanization (urban residences are more energy intensive than rural houses) building vintages (new buildings are subject to stricter energy codes), increased levels of comfort for heating and cooling, increased penetration of water heating, space heating, and cooling equipment, and higher appliance adoption rates as well as more recent appliance vintages.

China has been rapidly building new urban residential and commercial buildings over the past two decades. Annual completed new urban building floorspace (excluding country-level and

[9] Public buildings are included in the commercial building sector.

rural areas) in China increased on average 14% per year between 1990 and 2014, reaching 4,208 million square meters (m^2) in 2014 (Figure 1-10). After 2014, annual completed building floorspace stayed flat, or slightly decreased, reaching 4,135 million m^2 in 2018. Tightening of financing availability, a surplus of building space in some cities, new policies in some cities requiring higher down payments on second properties, bans on purchases by non-city residents, and prohibitions on third property purchases helped to slow the growth of new construction.

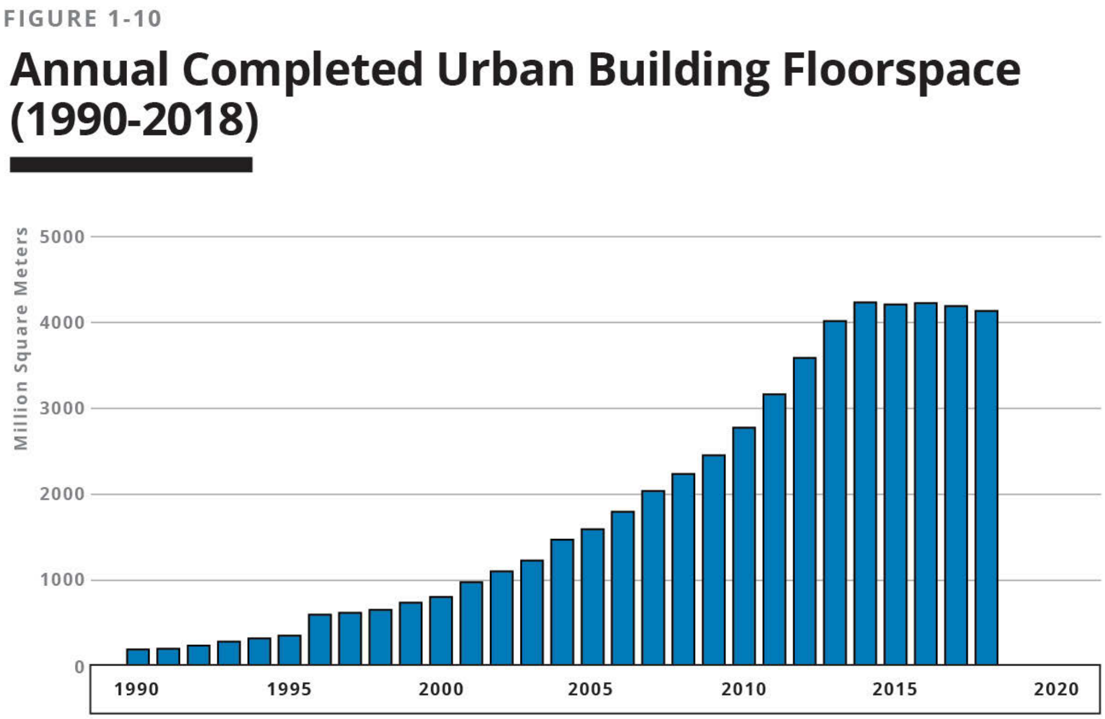


Figure 1-10. Annual Completed Urban Building Floorspace (1990-2018)
Source: NBS, various years (a).
Note: does not include county-level and rural areas.

Energy used to heat, cool, cook, and power appliances and equipment in residential and commercial buildings increased during this period due to China's growing middle-class, improved standard of living, and rapid urbanization. Figure 1-11 shows that major electricity-consuming household appliances, such as air conditioners and color TVs exceeded more than 100% saturation rates in urban households, with both reaching more than 120 units per 100 households in 2018. Other appliances, such as refrigerators and clothes washers were almost 100% saturated in urban households in 2018. In rural households, color TVs already exceeded 100% saturation, reaching 120 units per 100 rural households. The ownership of refrigerators and clothes washers has been increasing rapidly over the past 20 years, reaching around 90% saturation rate in 2018. Air conditioners are one of the newly-added major appliances in rural households, growing about 20% per year between 2010 and 2018 and reaching more than 65% saturation in 2018. The increase in appliance ownership has driven an increase in annual per capita electricity consumption in households, which grew by 45 times between 1983 and 2016.

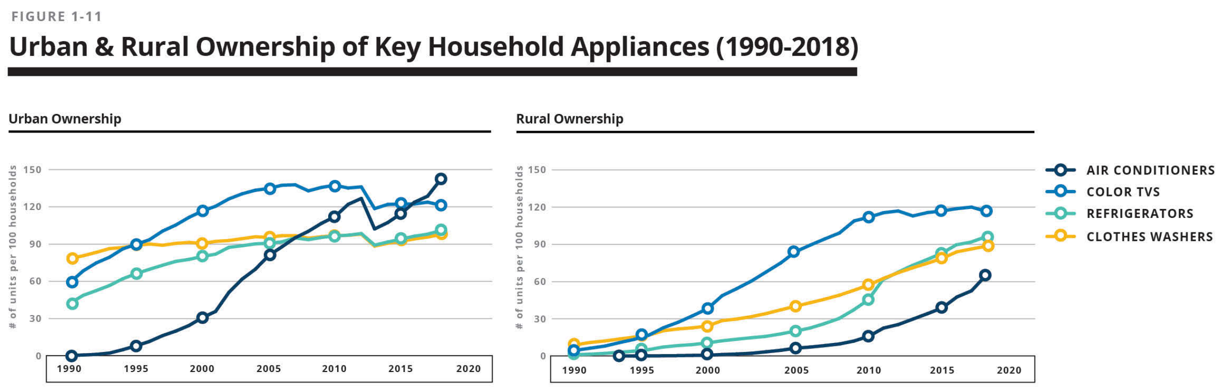


Figure 1-11. Urban & Rural Ownership of Key Household Appliances (1990-2018)
Source: NBS, various years (a); NBS, 2019b.
Note: 2013 and 2014 data are from the urban household income and living status survey conducted by the National Bureau of Statistics.

Transport Sector

Energy use to transport China's residents as well as raw materials (e.g. coal), manufactured products, and other goods has increased significantly, growing from consumption of 28.95 Mtce - a 5% share - in 1980 to 368.54 Mtce – a 9% share - in 2018, or 9.7% on an adjusted basis.[10] Drivers of transport sector energy use include the share of passenger and freight travel by various modes as well as the vintage and efficiency of the various travel modes.

Historically, freight in China was transported primarily by rail (Figure 1-12), but with the expansion of river and coastal ports since the 1970s, water transport—the most efficient in terms of energy use per tonne-kilometer travelled—has expanded rapidly. Today, water transport (50% is international ocean freight transport) dominates freight transport with about a 50% share of total freight tonne-kilometers. The share of freight transported by rail dropped from 40% in 1990 to 14% in 2018. Early data on road freight haulage is incomplete, but with expanded statistical coverage after 2005, the importance of road freight has become apparent. As rail lines often running at capacity, road movement has become more important, particularly for shipments of crucial materials such as coal. Rail freight today remains primarily for bulk materials such as coal, cement, and grain, but accounts for only 14% of total shipments.

[10] The values presented here are the official figures for the "Transportation, Storage and Post," which understates the actual amount used for transport services. In China, gasoline, which is almost entirely used in vehicles and thus for transportation services, is allocated to the sectors in which it is consumed instead of all to the transport sector. Figure 1-17, Composition of China's Petroleum Use (2017) below provides an adjusted view.

Railroads still carry a plurality of intercity passenger travel and the proliferation of high-speed rail lines over the past decade has maintained the high demand for rail travel over air travel. In 2018, railroads accounted for more than 40% of total passenger travel (in billion passenger-kilometers), up from an all-time low of 29.4% in 2012. Even so, as incomes have grown and the domestic air networks expanded, passenger travel by air increased sharply, accounting for 31% of total passenger-kilometers travelled in 2018.

The extensive network of highways built in the last 20 years has also led to increased demand for road travel and in 2018 highway passenger kilometers represented 27% of total passenger kilometers traveled (intercity only). Ownership of passenger vehicles (i.e. all non-freight vehicles) grew 20% per year between 2005 and 2018, reaching 41 units per 100 urban households from virtually none just 20 years ago – and still far below the 190 units per 100 households in the U.S. (Bureau of Transportation Statistics, 2017) and 106 units per household in Japan (Miller 2017). Rural ownership of passenger vehicles began to increase in the last five to eight years, reaching over 22% penetration in 2018.

FIGURE 1-12

Freight Movements by Mode (1950-2018) **Passenger Travel by Mode (1950-2018)**

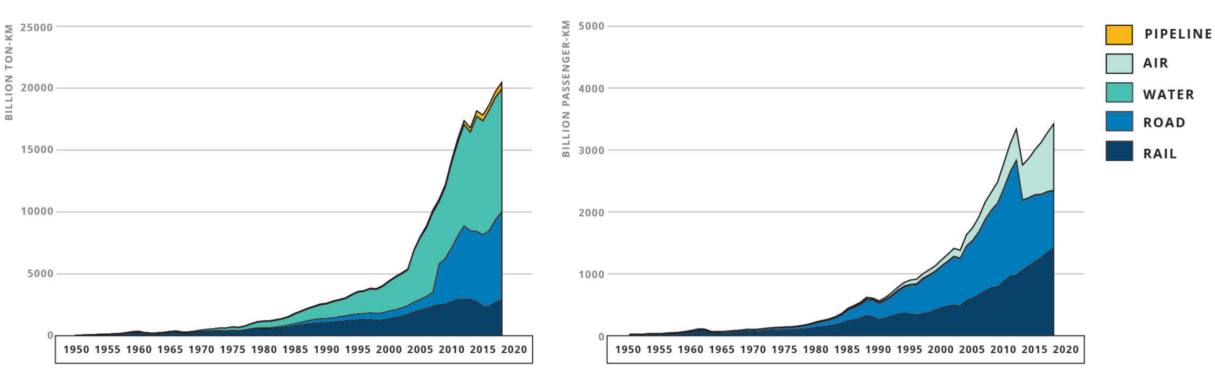


Figure 1-12. Freight Movements and Passenger Travel by Mode (1950-2018)

Source: NBS, various years (a).

Notes: 1) Data on highway transport for 1949-1978 include freight carried by transportation work units only. Subsequent data also include freight carried by vehicles belonging to other types of work units, e.g., industrial and agricultural. Data for 1984 and later years further include freight carried by private motor vehicles. 2) Inland waterway shipping data are not broken out after 1993, but are derived from Total and Ocean data. 3) Statistical boundaries of freight and passenger transport by highway and waterway were adjusted in 2008. 4) 2013 freight movement data and passenger travel data were from the 2013 Special Economic and Statistical Investigation of Transport Sector, and statistical boundaries were adjusted. 5) Water freight transport includes inland waterway transport and international ocean transport. 6) Data presented in charts are only for intercity freight and passenger transport, not intracity transport.

China's electric vehicle market began to grow in 2011, gained momentum in 2014, and was further boosted in 2015 with the promulgation of *Made in China 2025*, the government's 10-year plan to upgrade certain manufacturing sectors including electric vehicles (see Chapter 2).

The sales of new energy vehicles (NEVs), which includes battery electric vehicles, hybrid vehicles, fuel-cell electric vehicles, hydrogen vehicles, and other new energy vehicles grew 114% per year on average from 2011 to 2018 (Figure 1-13). Most of the NEV sales in China are battery electric vehicles, which represented 78% of the total 2018 NEV sales of 1.2 million vehicles, up from 62% for 2017. In 2016, China had 160,000 new energy buses, 18,000 new energy taxis, and 94,000 new energy city distribution vehicles (Xinhua Net, 2017a) with a goal of a combined total of these vehicles of 600,000 in 2020 (MOT, 2018). The sales of NEVs represented 4.4% of the Chinese automobile market of about 23.7 million vehicles sold in 2018, a higher share than in the U.S. (where the 361,000 EVs sold represented about 2% of total vehicle sales) but less than Europe (where the 950,000 EVs were sold represented over 6% of total vehicle sales). As of July 2019, China's new energy vehicles accounted for almost 6% of China's passenger car market.

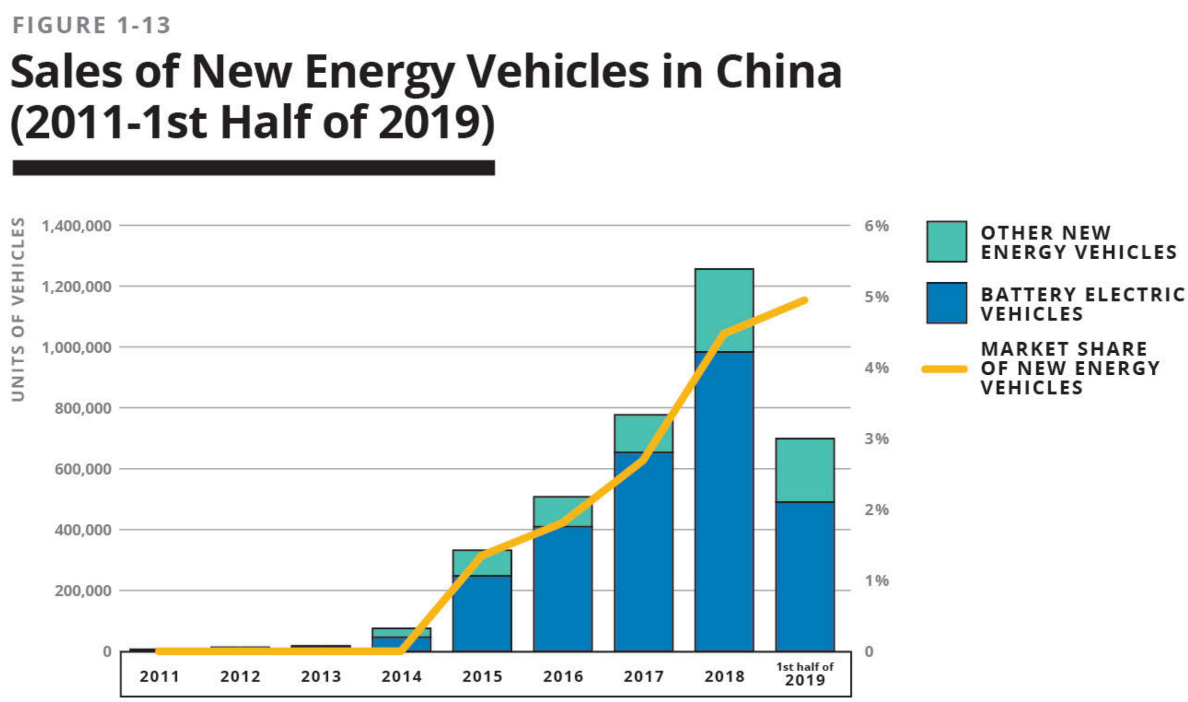


Figure 1-13. Sales of New Energy Vehicles in China (2011-1st Half of 2019)
Sources: Chinese Government, 2019; Xinhua Net, 2017b; Yang, 2015; Sohu News, 2014; Gasgoo News, 2013.
Note: Other New Energy Vehicles includes hybrid vehicles, fuel-cell electric vehicles, hydrogen vehicles, and other new energy vehicles.

Industrial Sector

Despite a recent slowdown in China's GDP growth and industrial activity, demand for energy intensive raw materials and products continues to increase due to urbanization and infrastructure construction (sometimes bolstered by national and local economic stimulus measures), the associated increase in domestic commodity consumption, and manufacturing exports. Though China's industrial energy efficiency has improved over the past decade, the energy intensities of China's major industrial subsectors generally lagged behind international levels less than a decade ago (Li, 2010; International Energy Charter,2018), although new facilities often have internationally state-of-the art equipment.

China's industrial sector[11] is not only the largest economic sector by far in terms of primary energy consumption but its share of total energy use has remained relatively constant, fluctuating between 67% and 73% since 1980 and settling at 70% from 2013 to 2018.[12] In 2018, China's industrial sector primary energy consumption of 2983 Mtce (87.42 EJ) was larger than the ***total*** national energy consumption of every country worldwide (including all European countries combined), except for the U.S. (BP, 2019b).

China's industrial sector transforms raw materials into products that build the country's cities and infrastructure. In addition, China is a key global manufacturing center. China tracks the production and energy consumption associated with 30 industrial sectors. Among those products, a few are not only very energy-intensive but also produced on a massive scale including iron ore, crude steel, cement, aluminum, and glass. Other energy-intensive industrial products manufactured in China include chemicals such as ethylene and ammonia, petrochemicals, machinery, textiles, food, paper and paper products, transport equipment, and wood and wood products.

China is the largest cement producer in the world, growing from 30% of global production in 1995 to 56% in 2019 (USGS, various years). Cement is mainly consumed domestically in China, with 2017 exports of 12 Mt, or only 1% of total production (China Customs, 2019). After years of continued growth to support domestic infrastructure expansion and economic growth, China's cement production reached a peak in 2014, producing about 2,500 Mt of cement. After 2014, cement production in China declined at 3% per year on average from 2014 to 2018, reaching 2,200 Mt in 2018 (Figure 1-14). However, the latest data show that China's cement production increased 4.4% in 2019 compared to 2018 after four years of decline.

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[11] Industrial sector refers to the secondary sector of China's economy, which includes mining, manufacturing, and water production and distribution. Within manufacturing, there are the following main sub-sectors: wood and wood products; transport equipment; non-specified industry; paper, pulp, and printing; food and tobacco; textiles and leather; petrochemicals; machinery; non-metallic minerals; chemicals and chemical products; and metals. In this report, industrial sector energy use is also combined with energy use of agriculture and construction sectors, unless noted otherwise.

[12] Note also that the share of secondary sector (mining, manufacturing, construction, power, heat, natural gas, and water production and supply) value added in China's total GDP has also remained relatively constant at about 40% between 1990 and 2018 (see Chapter 2).

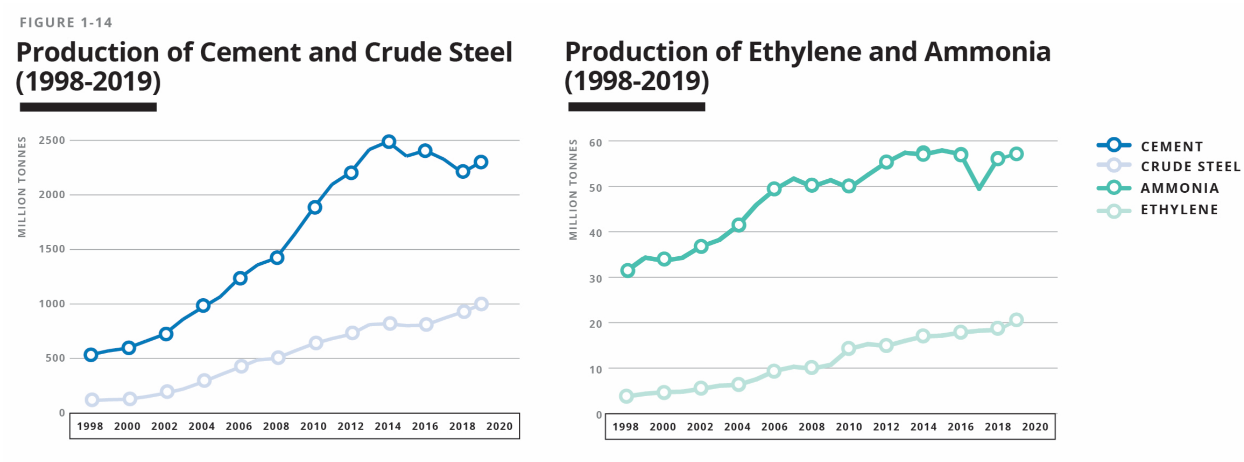


Figure 1-14. Production of Cement, Crude Steel, Ethylene, and Ammonia (1998-2019)
Source: NBS, various years (a).

Globally, China also produced 62% of pig iron and 52% of crude steel in 2019. Similar to the trend in cement production, crude steel production increased at 14% per year between 1998 and 2013. Between 2013 and 2016, crude steel production decreased -0.2% per year. From 2016 to 2019, crude steel production in China increased again, growing at 7% per year. The share of net exports dropped slightly during the first half of 2019 compared to the first half of 2018, from 6% to 5.5%. The growth in total steel output during the past two years is largely due to the increased market price of steel products driving up production after the capacity cuts in the Chinese steel sector.

Figure 1-15 shows China's steel imports, exports, total steel production, and net exports as a share of total steel production since 2009 (International Trade Administration 2019a and 2019b). China's exports of steel peaked in 2015 when 110 Mt were exported, 13 Mt were imported, and net exports were 97 Mt, or 12% of China's total steel production. Since then, exports of steel have dropped to 67 Mt in 2018 with net exports of 53 Mt that year, just under 6% of China's total steel production and around 12% of total world steel traded volume that year (China Customs 2019; World Steel Association, 2019). Net exports for the first half of 2019 are similar to those of the first half of 2018.

Ethylene is one of the most important chemicals and it is the building block for a large number of chemical products, including plastics, polymers, rubber, fibers, and solvents. Its production in China grew 10% per year between 1998 and 2013 and then slowed, increasing only 3% per year on average from 2013 to 2018. By 2019, China's ethylene production reached 18.4 Mt, or 11% higher than the annual production in 2018 (NBS, 2020).

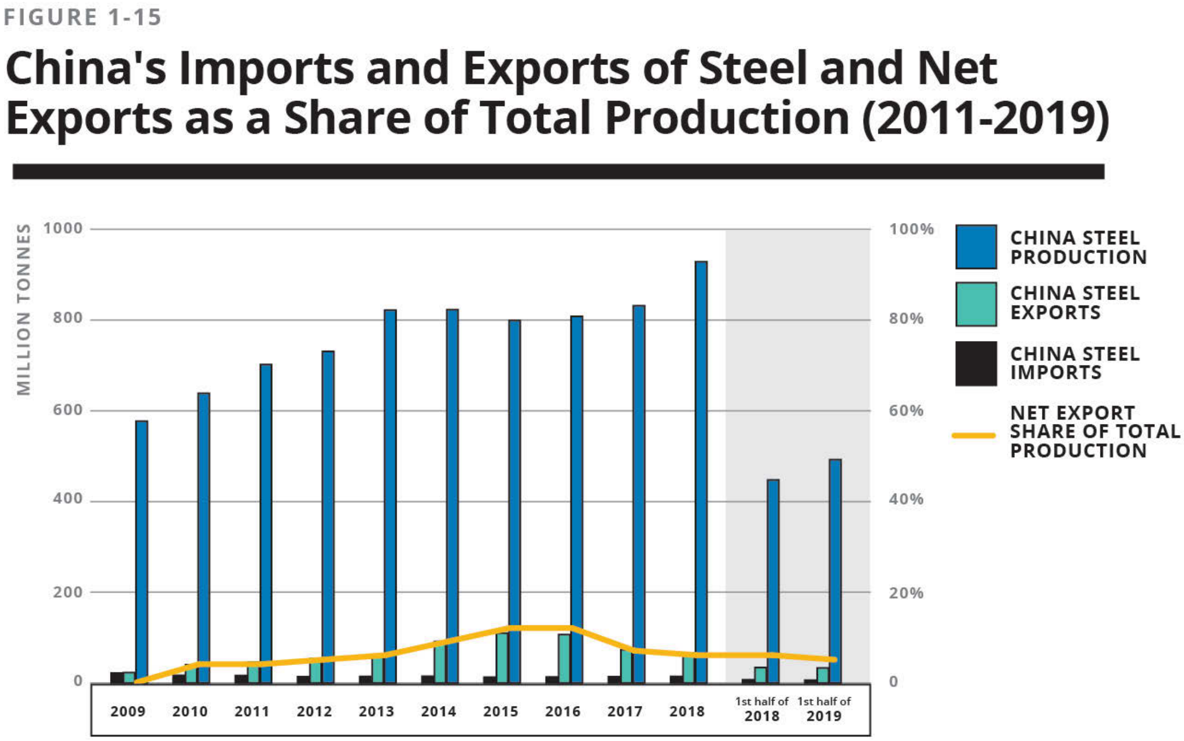


Figure 1-15. China's Imports and Exports of Steel and Net Exports as a Share of Total Production (2009-First Half of 2019).
Source: International Trade Administration, 2019a and 2019b.

Ammonia in is mostly used in the production of fertilizers to support the agricultural needs of China's growing population. Ammonia production grew steadily at 4% per year from 1998 to 2015. Ammonia production decreased slightly in 2016 and dropped quite significantly (-13%) in 2017 as a result of reduced fertilizer production. Ammonia production increased in 2018 back to the level of 2016.

Compared to 2018, production of most industrial products in China has increased during 2019. Table 1-2 shows that of 40 selected industrial commodities, 34 experienced production increases in 2019. The commodities range from energy-intensive intermediate products such as cement and steel to finished products such as photovoltaic cells, residential freezers, and air conditioners (NBS, 2020).

Within China's manufacturing sector, energy use for production of energy-intensive industrial commodities has increased, growing from 84% of total manufacturing energy use in 2000 to 87% in 2017. Energy use for production of the six most energy-intensive industrial commodities (ferrous metals, chemicals, non-metallic minerals, non-ferrous metals, petroleum refining, and coking) increased even more, growing from 72% of total manufacturing energy use to 78% (NBS, 2019b).

Table 1-2. Production of Selected Industrial Commodities in China, 2018 Compared to 2019

Industrial Commodity	Output 2018	Output 2019	Increase
Industrial Boilers (Evaporation ton)	322,293	393,853	22.20%
Photovoltaic Cells (10000 kw)	9,605	12,862	33.91%
Lead (10000 tons)	511.3	579.7	13.38%
Synthetic Fiber (10000 tons)	4,563	5,433	19.07%
Chemical Fiber (10000 tons)	5,011	5,953	18.79%
Copper Products (10000 tons)	1715.5	2017.2	17.59%
Residential Freezers (10000 sets)	1704.5	2,172	27.41%
Ethylene (10000 tons)	1841	2,052	11.48%
Aluminum Oxide (10000 tons)	7,253	7,247	-0.08%
Rolled Steel (10000 tons)	110,552	120,477	8.98%
Aluminum Alloy (10000 tons)	796.9	942.1	18.22%
Primary Plastic (10000 tons)	8,558	9,574	11.87%
Lithium Ion Batteries (10000 units)	1,398,714	1,572,184	12.40%
Crude Steel (10000 tons)	92,826	99,634	7.33%
Flat Glass (10000 weight cases)	86,864	92,670	6.68%
Air Conditioners (10000 sets)	20,486	21,866	6.74%
Pig Iron (10000 tons)	77,105	80,937	4.97%
Soda Ash (10000 tons)	2,621	2,888	10.20%
Synthetic Rubber (10000 tons)	559	733.8	31.27%
Home Refrigerators (10000 sets)	7,877	7,904	0.35%
Ferroalloy (10000 tons)	3,123	3,658	17.11%
Electrolyzed Aluminum (10000 tons)	3,580	3,504	-2.12%
Ten Kinds of Nonferrous Metals (10000 tons)	5,688	5,842	2.70%
Crude Iron Ore (10000 tons)	76,337	84,436	10.61%
Cement (10000 tons)	217,667	233,036	7.06%
Chemical Fertilizers, Manufactured (10000 tons)	5,460	5,625	3.03%
Alternating Current Motors (10000 kw)	26,459	28,733	8.59%
Caustic Soda (100%) (10000 tons)	3,420	3,464	1.29%
Refined Copper (10000 tons)	902.9	978.4	8.36%
Plastic Products (10000 tons)	6,042	8,184	35.45%
Sulfuric Acid (100%) (10000 tons)	8,636	8,936	3.47%
Zinc (10000 tons)	568.1	623.6	9.77%
Aluminum Products (10000 tons)	4,555	5,252	15.32%
Machine-made Paper and Paperboards (10000 tons)	11,661	12,515	7.33%
Phosphate Ore (10000 tons)	9,633	9,332	-3.12%
Tires (10000 lines)	81,641	84,226	3.17%
Silk and Woven Fabric (10000 m)	51,563	48,167	-6.59%
Synthetic Detergents (10000 tons)	928.6	1000.9	7.79%
Cloth (100 million m)	498.9	456.9	-8.42%
Chemical Pesticides (10000 tons)	208.3	225.4	8.21%
Newsprint (10000 tons)	149.7	108.9	-27.25%

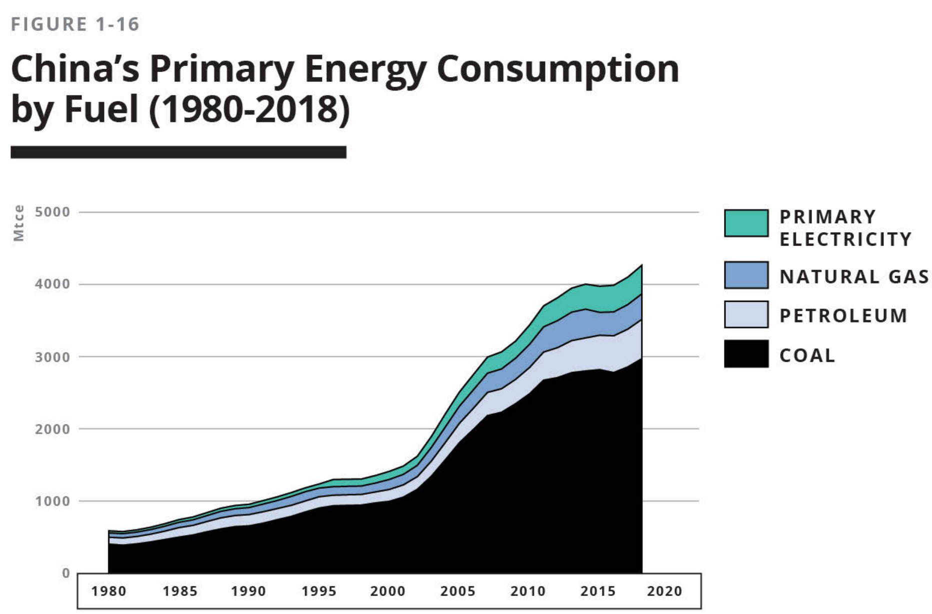
Source: NBS, 2020.

Note: Ten Kinds of Nonferrous Metals includes: copper, aluminum, lead, zinc, nickel, tin, antimony, magnesium, titanium, and mercury.

Energy Consumption by Fuel

China's buildings, transport, industry, and other end-use sectors predominantly rely on fossil fuels for primary energy (including electricity from coal- and natural gas-fired power plants), with this reliance dropping slightly over the years from 99% in 1980 to 94% in 2018. Figure 1-16 shows that of these fossil fuels, coal dominates with a current share of 64%, followed by petroleum (21%), and natural gas (9%).

The use of coal and coking products for production of thermal power soared between 1980 and 2017, increasing from 27% to 48%. The industrial sector is the second largest coal-user in China, after thermal power, and accounted for 40% of total coal and coking products used in 2017. About 7% of total coal and coking products was used for heating supply in 2017. The share of coal decreased significantly in the buildings sector in China, dropping from 23% in 1980 to 5% in 2017.



China's Energy Consumption by Fuel (2017-2018) (Mtce)

	2017	2018	% Change
Primary Electricity	229	255	11%
Natural gas	314	370	18%
Petroleum	844	899	7%
Coal	2,712	2,740	1%
Total	544	624	14.9%

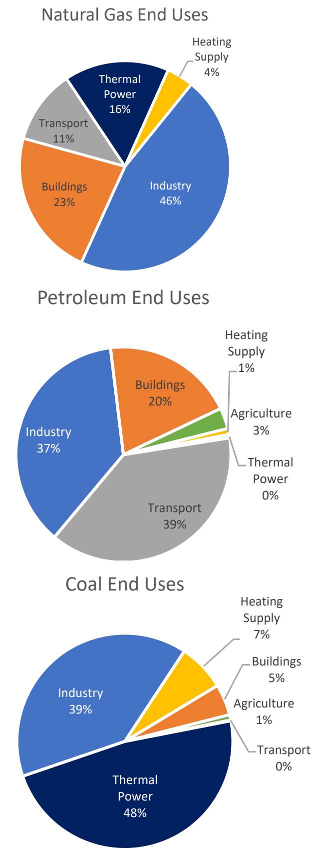


Figure 1-16. China's Primary Energy Consumption by Fuel (1980-2018) and by End Use Sector (2017)
Sources: China Energy Group, 2016; NBS, various years (b).
Notes: 1) Coal includes both direct use of coal and use of coking products, e.g., coke and coke oven gas. 2) Primary electricity includes hydro, solar, wind, geothermal and nuclear power. Primary electricity consumption in physical units is converted to standardized energy units based on the Direct Equivalent method. Note that primary electricity growth between 2017 and 2018 using China's Power Plant Coal Consumption method was 10.3% and total primary energy growth was 3.3%. 3) Construction sector is included in industrial sector; agriculture sector is also included in industry for natural gas end-use shares. 4) For petroleum end-use shares, figures are reported on an unadjusted basis based on official energy accounting practices in China. 5) Natural gas end-use consumption includes both natural gas and LNG.

The primary driver of growth in China's petroleum use has been transportation demand and the use of petroleum as feedstock in the petrochemical industry and for non-energy uses such as asphalt and lubricants. The share of petroleum in total primary energy use has been relatively consistent and was about 21% in 2018. After fairly slow growth in the 1980s, petroleum demand in China began to rise steadily and reached nearly 570 Mt in 2017, with further increases to over 600 Mt in 2018.

China's official figures on petroleum consumption by sector understates the role of transportation in the demand mix, as petroleum consumption is allocated to the sector in which it is consumed instead of by the purpose of its consumption. For example, "Buildings" use of petroleum, which is largely composed of LPG consumption for cooking and water heating, also includes gasoline consumption by the occupants of buildings, thus inflating the building total. Figure 1-17 adjusts the official figures by moving all transport gasoline use to the transportation sector as well as jet fuel used in the public sector (e.g. government planes) to transportation as well. With this adjustment, transportation use of petroleum rises from an "official" 38% to 52%, with gasoline and diesel consumption nearly equal. Jet fuel consumption has been increasing steadily with the expansion of China's domestic and international air fleet, and fuel oil use powers the shipping fleet.

Even so, personal and discretionary use of private cars (defined here as "privately owned sedans") still remains a fairly small proportion of total oil use, at 17% in 2017, although the growing fleet now accounts for 74% of total gasoline consumption in the country. In 2012, by contrast, private cars accounted for 11% of total oil use, and 57% of gasoline use.

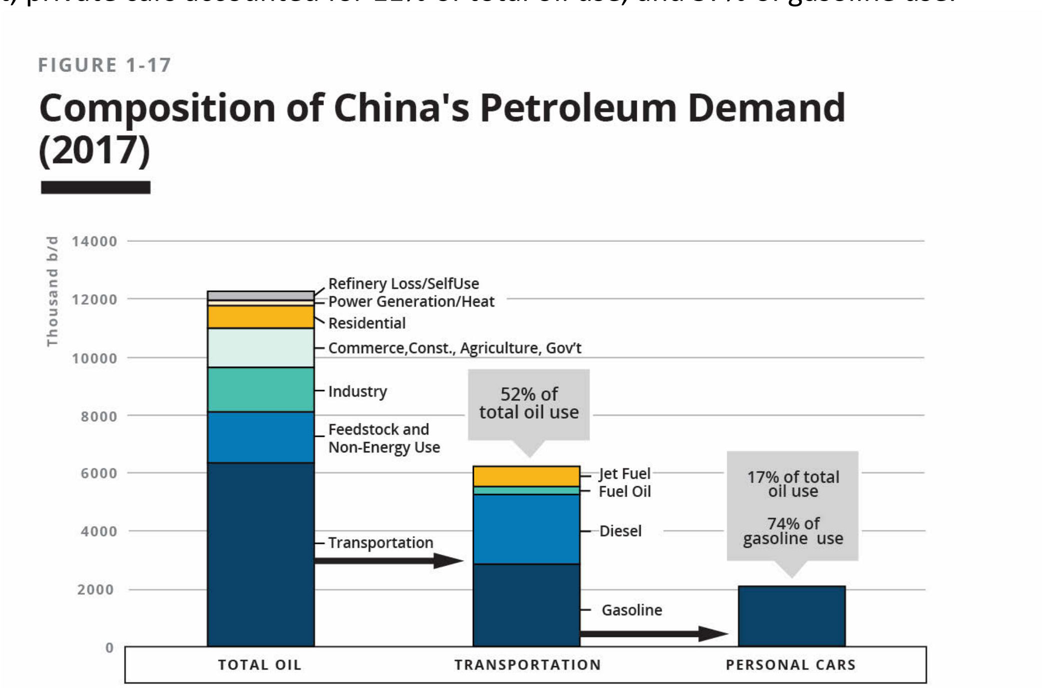


Figure 1-17. Composition of China's Petroleum Use (2017)
Note: Demand has been adjusted from the official figures by moving all gasoline for transportation to the transport sector and jet kerosene for the public sector from buildings to transport.

China's consumption of natural gas has been growing more than 10% per year since 2001 and comprised 9% of the total primary energy use in 2018. The increased use of natural gas is largely driven by air quality and public health concerns related to coal combustion. Traditionally natural gas was largely used in Chinese industries as a fuel or feedstock. In recent years, due to the Chinese government's efforts in its Winning the Battle for a Blue Sky Program (see Chapter 2) to improve air quality, natural gas has been increasingly used in the buildings sector, the thermal power sector, and to provide heat in district heating networks. As of 2017, 43% of the natural gas was consumed in industry, 23% was consumed in buildings, 18% was used for heating supply, and 12% was used for power generation (Figure 1-24). It is also worth noting that between 2017 and 2018, the largest increase in natural gas consumption was in the thermal power and heating supply sectors as a result of the government target of shifting from coal to gas and from coal to electricity.

Primary electricity – that is, electricity produced by hydro, solar, wind, geothermal, nuclear power, and other sources not generated through combustion transformation and converted to standardized energy units using the direct equivalent method[13] – has grown from a 1.2% share in 1980 to 6% in 2018. The growth in primary electricity consumption has closely tracked the expansion of solar, wind, and other renewable electricity capacity, which have been rapidly expanding since 2010, with an increase of 11% in generation from these primary electricity sources between 2017 and 2018.

To expand the role of primary electricity in the national energy mix, China established a national target for the share of non-fossil energy to be 15% by 2020 and 20% by 2030.[14] This target is expressed and calculated by converting primary electricity to standardized energy units using the Power Plant Coal Consumption method. Based on the figures available in China's national energy balance, the share of non-fossil energy has risen steadily since 2012, reaching 13.3% in 2017 and 14.3% in 2018 (Figure 1-18) (Liu, 2019).

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[13] To convert primary electricity into standardized energy units such as Mtce, China uses the "Power Plant Coal Consumption" method based on the amount of energy used in power plants in a year, and thus treats primary electricity as if it were generated in a fossil-fuel power plant; unless otherwise noted, this report uses the Direct Equivalent method, adopted by the IPCC as well, that values primary electricity at its calorific value. For further details on these and other conversion conventions, see Lewis et al., 2015.
[14] This includes biomass power generation but excludes direct residential use of biomass.

FIGURE 1-18

China's Share of Non-Fossil Energy in Total Energy Consumption (2000-2018) and 2020 Goal

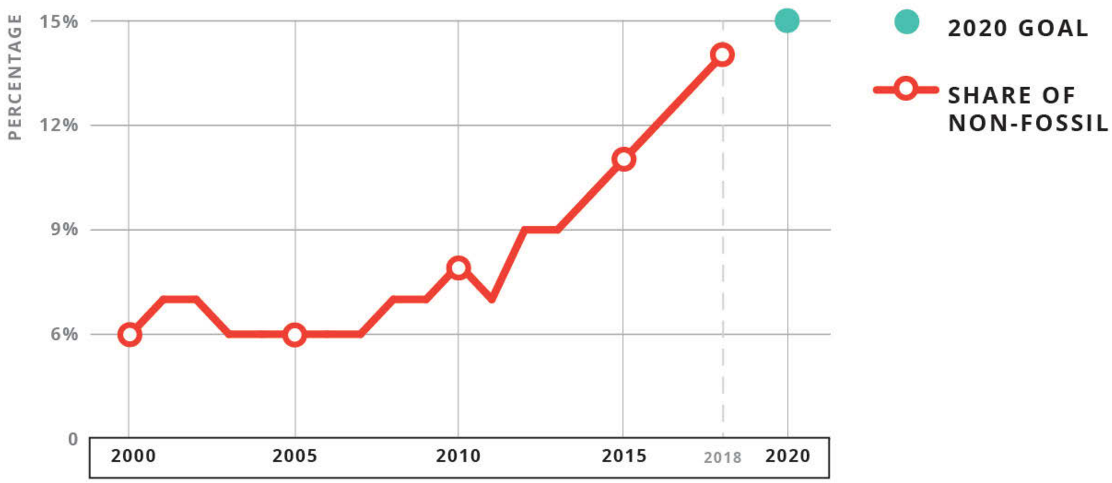


Figure 1-18. China's Share of Non-Fossil Energy in Total Energy Consumption (2000-2018) and 2020 Goal

Source: NBS, various years (b).
Note: Based on China's Power Plant Coal Consumption method.

Figure 1-19 shows that the structure of building final energy use has changed significantly over the last three decades. The share of direct coal use in both commercial and residential buildings decreased sharply from 73% in commercial buildings and 93% in residential buildings in 1980 to 35% and 17% in 2017, respectively. As a result of growing adoption of electric appliances and equipment, final electricity use in commercial buildings increased from 5% in 1980 to 39% in 2017; final electricity use in residential buildings grew from 1% to 27% during the same period.

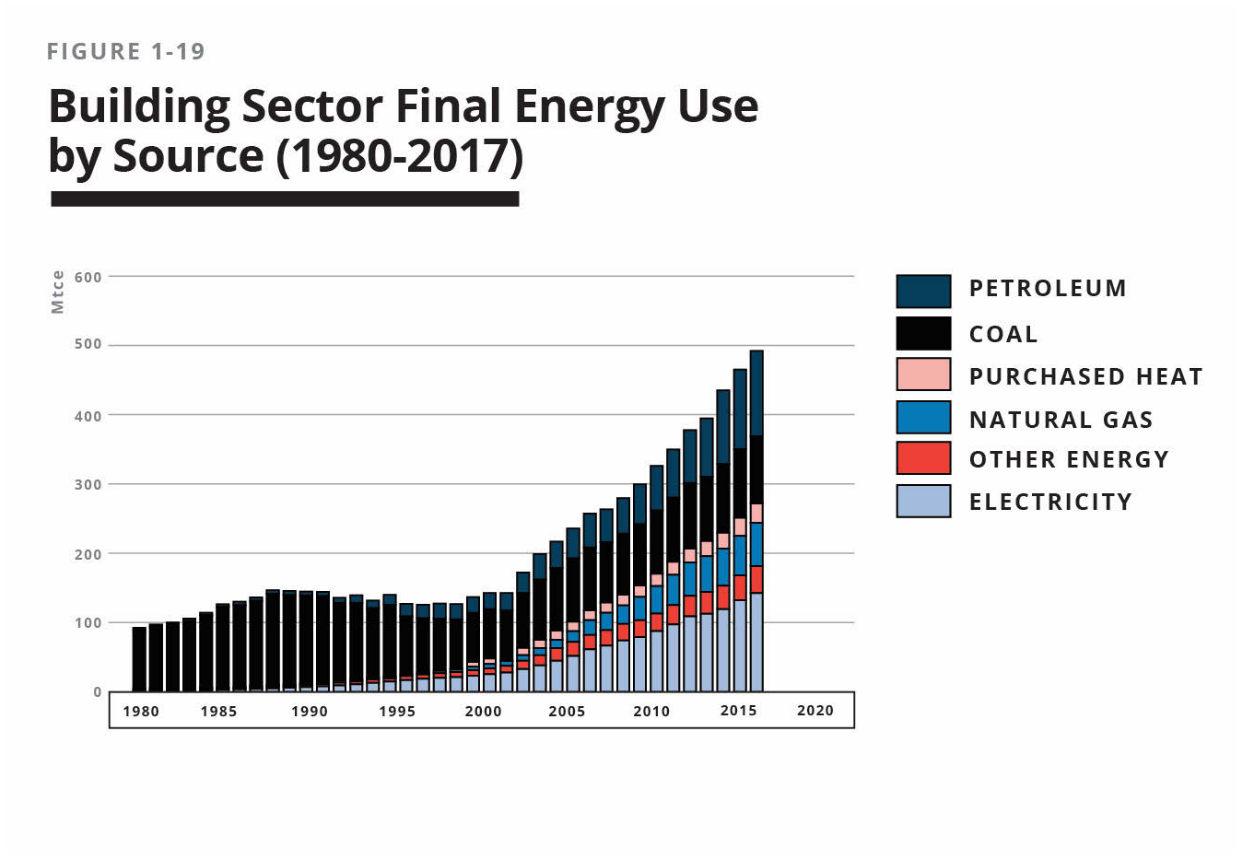


Figure 1-19. Building Sector Final Energy Use by Source (1980-2017)
Source: NBS, various years (b).
Note: Electricity is converted to standard energy units using China's Power Plant Coal Consumption method.

Energy use by fuel in the transport sector is largely dominated by petroleum products, such as gasoline, diesel, fuel oil, and kerosene. In 2017, petroleum products accounted for 82% of final transport sector energy use (Figure 1-20).[15] Direct use of coal declined to almost 1% of the total energy use in 2017. Natural gas consumption, including LNG for heavy trucks and CNG for buses and some taxis, has been growing and represents 9% of the total sector energy use. Direct electricity use in the transport sector increased to 4% in 2017.

China tracks the energy consumption associated with production of 30 manufacturing sub-sectors, which are shown in aggregate from 1995 to 2012 and by sub-sectors for 2013 to 2017 in Figure 1-21. Production of metals (mostly steel), chemicals, and non-metallic minerals (mostly cement) uses the largest shares of manufacturing energy.

[15] China's official figures on petroleum consumption by sector understate the role of transportation in the demand mix, as petroleum consumption is allocated to the sector in which it is consumed instead by the purpose of its consumption.

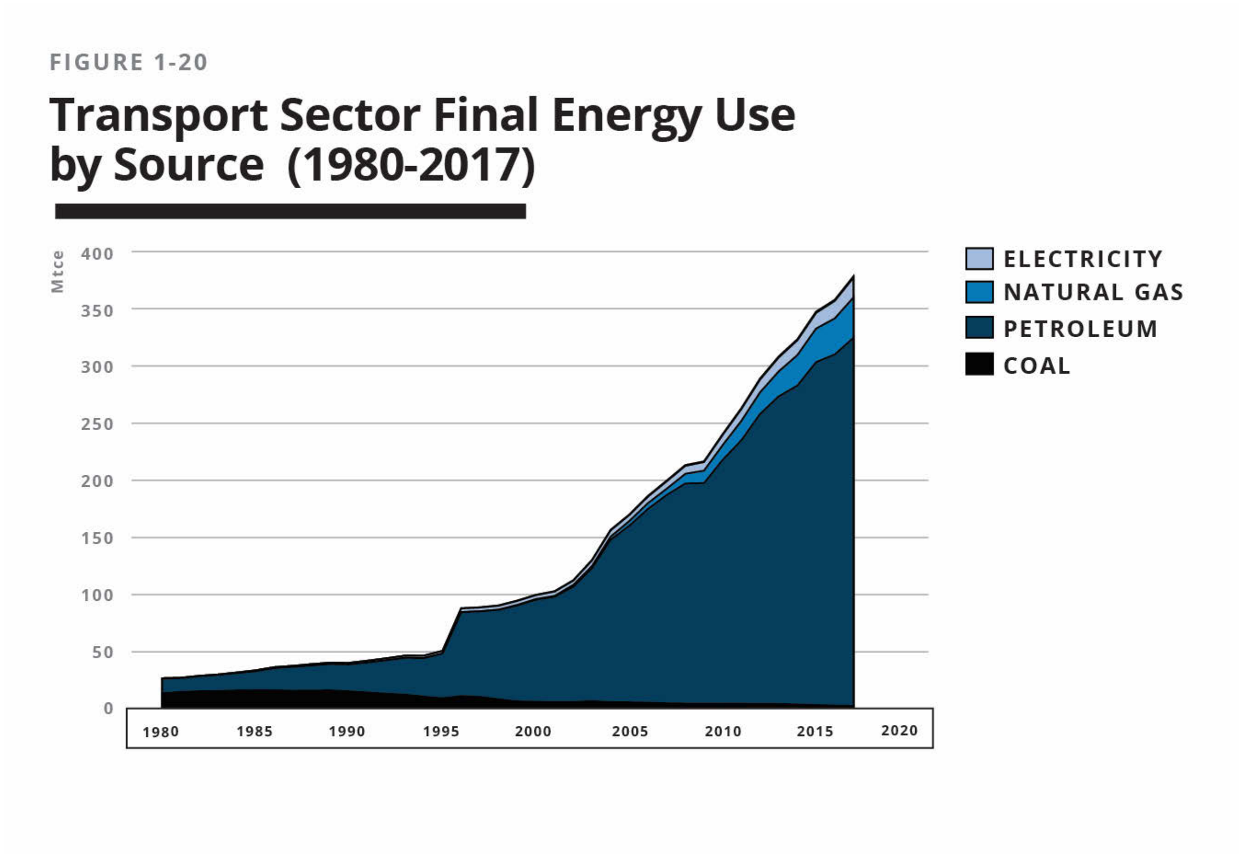


Figure 1-20. Transport Sector Final Energy Use by Source (1980-2017)
Source: NBS, various years (b).
Notes: 1) Electricity is converted to standard energy units using China's Power Plant Coal Consumption method. 2) Transport sector energy consumption values have undergone several revisions and the national figures have been revised to 1996, which explains the series discontinuity in that year.

Figure 1-22 shows the growth in China's industrial sector's final energy consumption by fuel source. While coal, coke, and coal gas are the predominant fuel sources used in China's industrial sector, their share has decreased from 66% in 1980 to 51% in 2017. Use of petroleum for industrial production has also declined from 17.4% in 1980 to 11.6% in 2017 while the share of natural gas has fluctuated slightly between 5.5% in 1980 to a low of 2.7% in 1998 and then 6.8% in 2017. The decreased reliance on coal and petroleum was replaced by increasing use of electricity, which grew from an 8.8% share in 1980 to 25% in 2017, with 70% of the electricity produced by coal. As such, industry is also the main source of the country's environmental pollutants, emitting 70–90% of atmospheric emissions of sulfur dioxide (SO_2), nitrogen oxides (NOx), and total suspended particulate matter in 2010—the primary drivers of air pollution in China's cities (MEP, 2014).

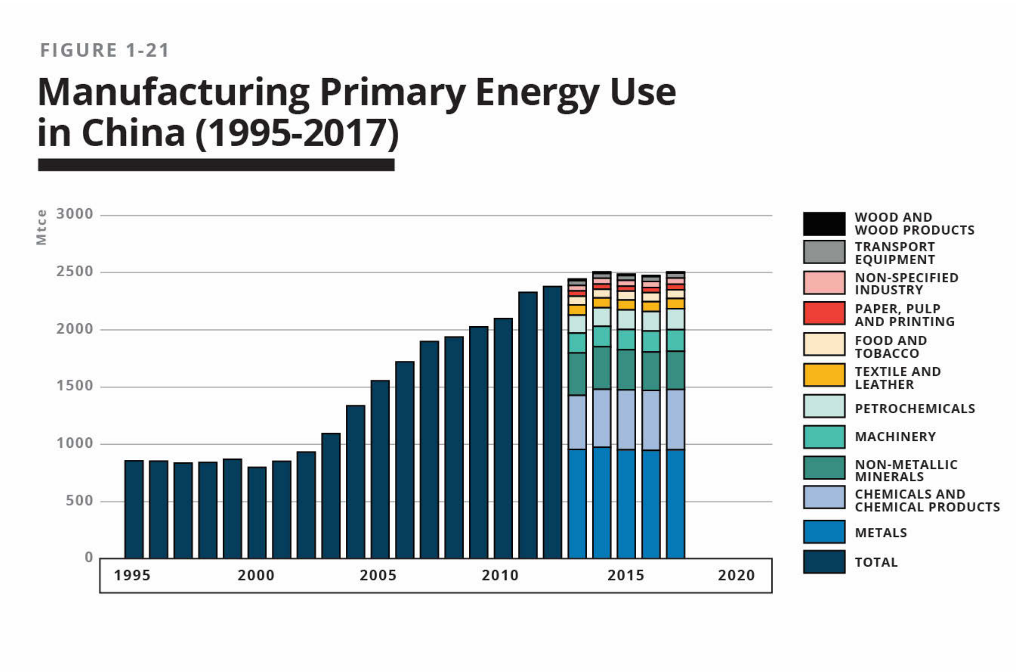


Figure 1-21. Manufacturing Primary Energy Use in China (1995-2017)
Source: NBS, various years (b).
Notes: 1) Electricity is converted to standard energy units using China's Power Plant Coal Consumption method. 2) National total manufacturing primary energy use for 1995-2012 was revised by NBS without providing details on revised sub-sectoral energy use; as shown in the figure, such level of detail is currently only available for 2013-2017.

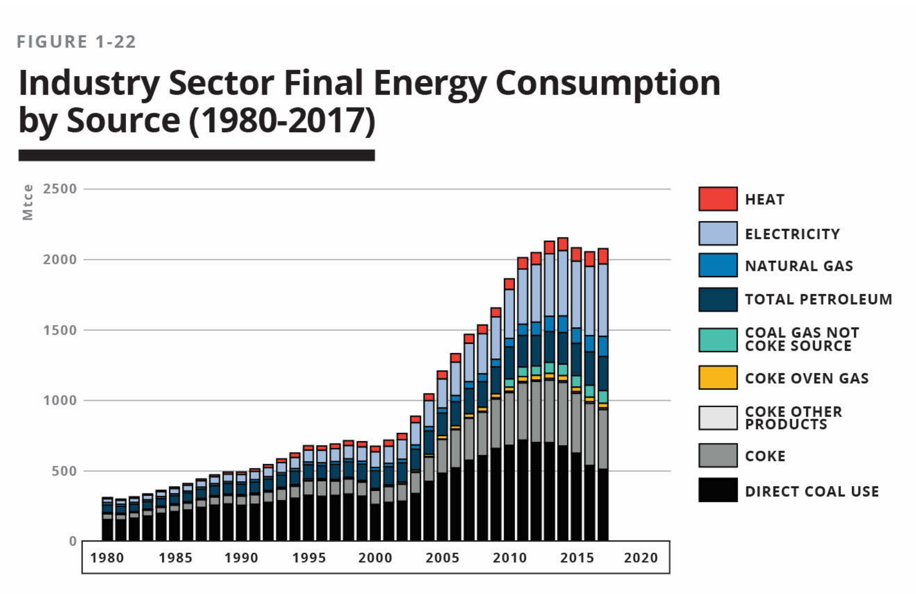
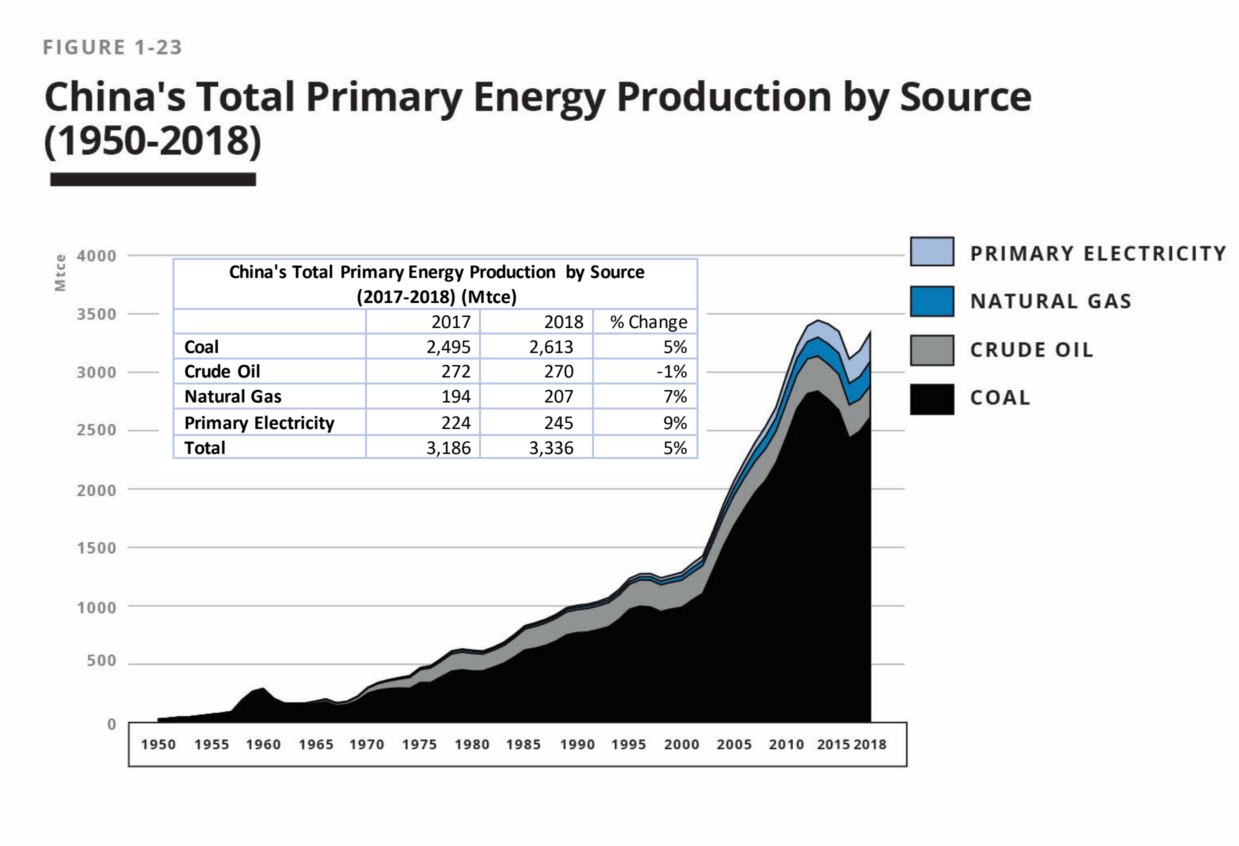


Figure 1-22. Industrial Sector Final Energy Consumption by Source (1980-2017)
Source: NBS, various years (b).
Note: The use of LNG is included with natural gas.

Primary Energy Production Trends

Coal has been and remains China’s dominant fuel in terms of primary energy production (Figure 1-23). The share of coal was highest in the 1950s and 1960s, exceeding 90% of total energy production. After that, coal’s share slowly decreased, reaching 77% in 2000. Since 2001, with China’s entry into the World Trade Organization, coal’s share increased and peaked at 83% in 2011-2012.



	2017	2018	% Change
Coal	2,495	2,613	5%
Crude Oil	272	270	-1%
Natural Gas	194	207	7%
Primary Electricity	224	245	9%
Total	3,186	3,336	5%

Figure 1-23. China’s Total Primary Energy Production by Source (1950-2018)
Sources: China Energy Group, 2016;. NBS, various years (b).

Even with rapid growth in natural gas and primary electricity production (e.g., wind, solar, nuclear) in recent years, coal production followed China’s total energy demand closely. In 2018, the share of coal in China’s total primary energy production was 78%, followed by 8.1% crude oil, 7.3% non-fossil electricity, and 6.2% natural gas.

In the first half of 2019, China’s coal production increased 4.3%, oil production increased 1% and natural gas production increased 9.7% compared to the first half of 2018 (NBS, 2019b).

FIGURE 1-24

China's Electricity Production by Source (1980-2019)

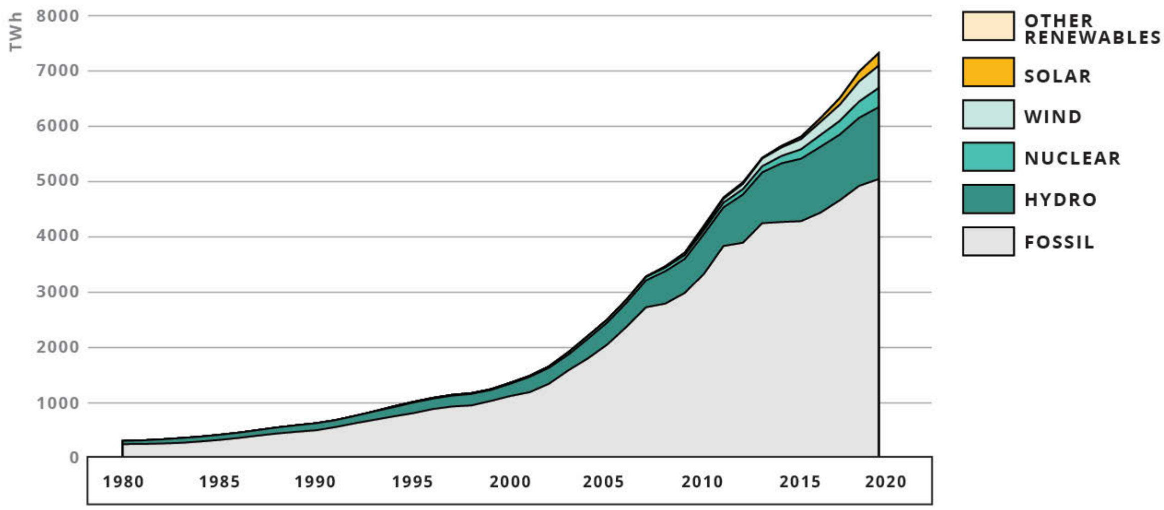


Figure 1-24. China's Electricity Production by Source (1980-2019)
Sources: China Energy Group, 2016; NBS, various years (b).
Note: Other Renewables includes biomass, geothermal, and others.

During the past three decades, China's electricity production has grown rapidly, increasing from 300 TWh in 1980 to 7325 TWh in 2019 (Figure 1-24). The period of the fastest growth in electricity production was from 2002 – 2007, with continuous annual average growth of more than 10%. By the end of 2007, total electricity production was 3,270 TWh, almost 11 times the 1980 level.

Fossil fuel still dominates China's electricity production, accounting for slightly more than 70% of total electricity production in 2018. Fossil fuels are dominated by the use of coal (91%), followed by natural gas (4%), followed by biomass (2%), and oil (0.03%). The share of non-fossil fuel generated electricity in China increased from 19% in 1980 to the current level of roughly 30%, comprised of almost 18% hydroelectric, and roughly 5% wind, 4% nuclear, and 3% solar.

With the commercial operation of China's first nuclear power plant, the Qinshan Nuclear Power Station, in 1994, the share of nuclear generated electricity has gradually increased from 1.6% in 1994 to 4.8% in 2019, as China continues to lead the world in deployment of new nuclear capacity. Wind generated electricity has surpassed electricity generated by nuclear power since 2013.

Although China is the largest producer and user of renewable electricity, recent strong growth in total electricity demand has led to expanded use of fossil fuel-based power. Between 2017 and 2018, fossil fuel-based electricity generation increased by 260 TWh, higher than growth in all non-fossil sources of electricity (221 TWh).

Figure 1-25 and Table 1-3 show that in 2018 China added 45 GW of solar power generation capacity, or 36% of the total added power capacity that year, exceeding the added thermal (coal and natural gas) power capacity (41 GW). Wind power capacity increased by 21 GW, representing 17% of the added power generation capacity. Nuclear power generation capacity increased by 8.8 GW (7%), closely followed by hydro power capacity 8.5 GW (7%). Overall, China added 83 GW of zero-carbon capacity (67% of all capacity additions) in 2018 (CEC, 2019a)

During the first three quarters of 2019, thermal capacity additions continued to increase at about the same pace as in 2018, while capacity additions of all of the non-fossil sources were less than the 75% level of 2018 additions, with solar additions significantly lower (CEC, 2019b).

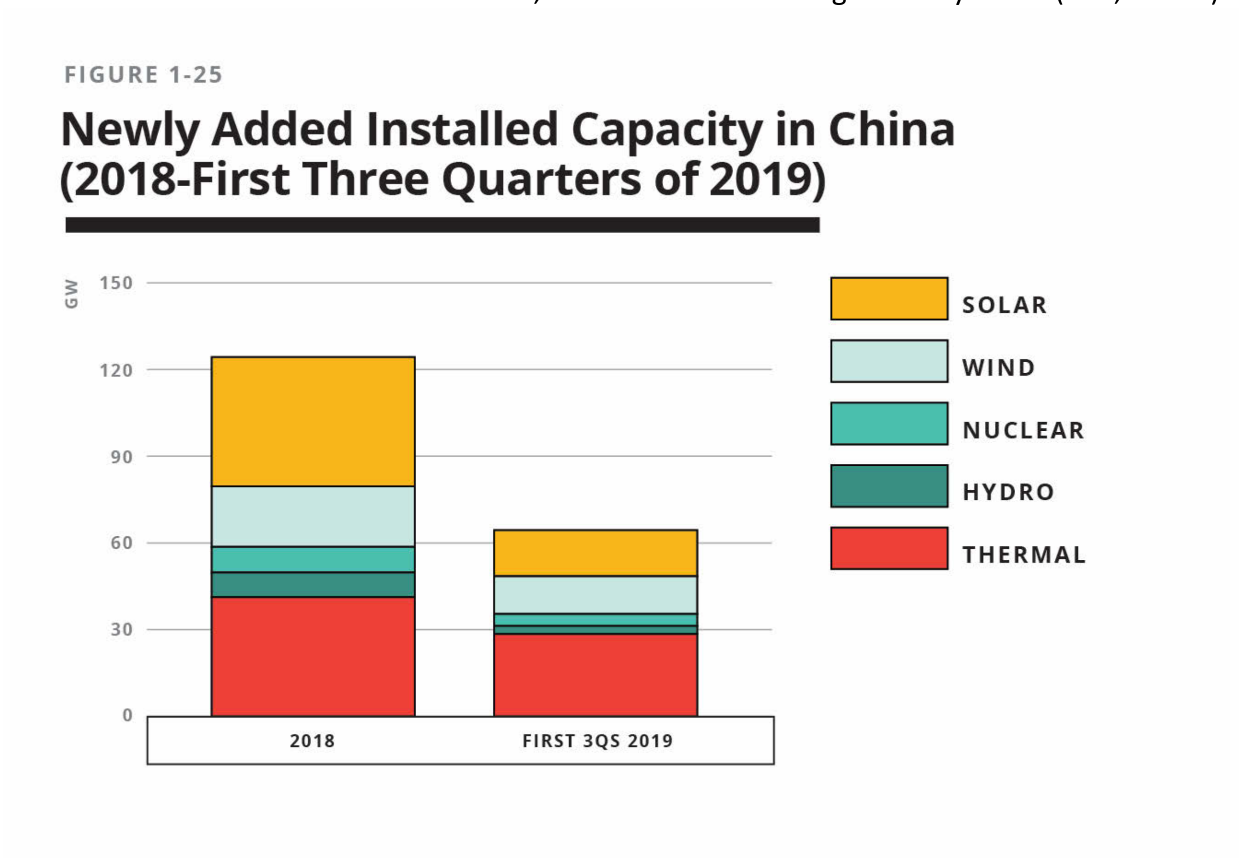


Figure 1-25. China's Newly Added Installed Electricity Capacity 2018 and First Three Quarters of 2019
Source: CEC, 2019a; CEC, 2019b.
Note: does not include biomass

Table 1-3. China's Newly Added Installed Electricity Capacity 2018 and First Three Quarters of 2019

	Newly Added Installed Capacity (GW)		Total Installed Capacity (GW)
	2018	3Q 2019	3Q 2019
Thermal	41.19	28.47	1170.25
Hydro	8.54	2.80	308.58
Nuclear	8.84	4.09	48.74
Wind	21.00	13.08	197.83
Solar	44.73	15.99	137.89
Non-Fossil	**83.11**	**35.96**	**693.04**
Total	**124.30**	**64.43**	**1863.29**

Source: CEC, 2019a; CEC, 2019b.
Note: does not include biomass

During the first half of 2019, thermal power generation in China has grown more slowly, with year-on-year growth compared to the first half of 2018 at only 0.2%. Non-fossil generation grew at a much faster rate, with year-on-year growth of 29% for solar, 23% for nuclear, 12% for hydro, and 11.5% for wind generation.

Policies aimed at reducing air pollution emissions, retiring inefficient capacity, and expanding the use of more efficient ultra-super-critical units have led to a steady reduction in the amount of coal consumed per unit of generation, from 356.4 gce/kWh in 2005 to a projected 312.8 gce/kWh in 2020 (Wu et al., 2019). Consequently, CO_2 emissions per kWh generated have fallen substantially along with emissions of SO_2, NOx, and particulate matter (Table 1-4). With the release of the new ultra-low emission standards for power plants (2015), emissions per kWh of air pollutants in 2020 are expected to be below those of the U.S. (Wu et al., 2019).

Table 1-4. China Coal Plant Emissions Factors

	2005	2010	2015	2020p
CO_2 (g/kWh)	986.9	851.7	795.2	791.3
SO_2 (g/kg coal	15.9	4.9	2.2	0.8
NOx (g/kg coal)	6.2	5.3	2.5	0.7
$PM_{2.5}$ (g/kg coal)	1.3	0.5	0.4	0.1
PM_{10} (g/kg coal)	2.4	0.8	0.5	0.2

Source: Wu et al., 2019
Note: p = projected

China's petroleum refining system is the second largest in the world after the U.S. and produces nearly the entire range of petroleum products required in the country. Growth in refining has been primarily driven by increased demand for transport fuels—gasoline, jet kerosene, and diesel—and by demand for feedstock (including naphtha) in the petrochemical industry (Figure 1-26).

FIGURE 1-26

China's Petroleum Refining by Product (1985-2017)

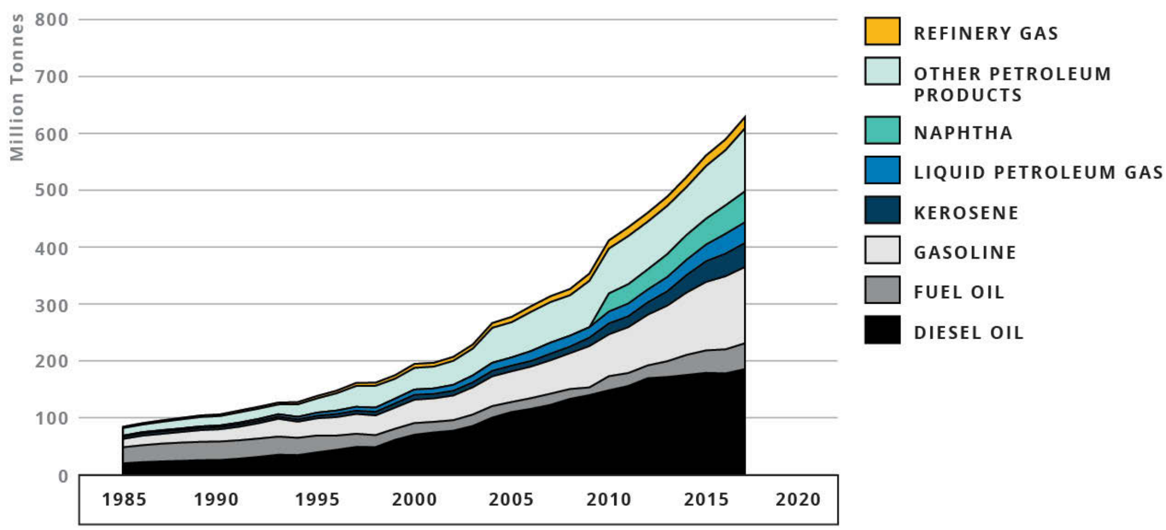


Figure 1-26. China’s Petroleum Refining by Product (1985-2017)
Sources: China Energy Group, 2016; NBS, various years (b).

Historically, diesel fuel - used both in freight hauling and in industry - has been the fuel in greatest demand, but as road hauling began to decline after 2015, growth shifted to gasoline for automobiles as the gasoline-powered fleet continued its strong expansion. The “diesel-gasoline ratio,” used in China as in indicator of the imbalance in the refining system between the two fuels, rose to a peak of 2.1 in 2008 (i.e. 2.1 tonnes of diesel produced for every 1 tonne of gasoline) but has since declined to 1.4 in 2016 and 1.25 in 2018.

Similarly, China’s refineries have gradually adjusted the production yield in the system through operational changes and changes in the crude oil slate from a high of 36% diesel yield in 2010 to 27.1% in 2018, and part of this reduction allowed the increase in jet kerosene production (both middle distillates), rising from 4.6% of the total in 2010 to 7.2% in 2018. The combined gasoline and naphtha yields (both light distillates) has climbed from 25.6% in 2010 to 29.9% in 2018.

China is a net importer of crude oil, natural gas, and coal, but the degree of import dependency varies greatly. Figure 1-27 and Table 1-5 provide information on China’s 2017 imports and exports of these energy commodities.

In 2018, crude oil imports accounted for 69% of the crude oil processed in domestic refineries, with the largest import volumes from Russia, Saudi Arabia, and Angola (favored for its light low-sulfur crude oil). China maintains a strategic diversity of dozens of crude oil suppliers to avoid over-reliance on a single source. In recent years, with the lifting of the U.S. crude oil export ban, China has begun imports from the U.S., which it overtook in 2017 as the largest crude oil importer in the world. Although in terms of volume, U.S. crude oil imports are fairly small, averaging 126,000 b/d from January to July 2019, a level 63% lower than in 2018, imports may further contract as China imposed an import tariff of 5% on U.S. crude starting in September 2019 (Tan and Zhang, 2019).

Natural gas imports have risen sharply along with demand as domestic production has been unable to expand commensurately. In 2017, natural gas imports (from both LNG and pipelines) accounted for 40% of domestic consumption, jumping to 45% in 2018 as the program to reduce the use of dispersed coal in northern China led to a large increase in demand. China's primary source of imported LNG is Australia, with whom it has long-term supply contracts, but it also buys LNG on the spot market. In 2016, China initiated spot LNG imports from the U.S., and in 2017 accounted for 15% of total U.S. LNG exports. The trade war that begin in 2018 undermined the growth trajectory with the imposition of a 10% tariff in 2018, and in 2019 shipments have fallen sharply as tariffs were further raised to 25% in June. The main source of pipeline gas is Turkmenistan though the Central Asia-China pipeline via Uzbekistan and Kazakhstan, which accommodates up to 55 billion cubic meters of flow annually. A new source of natural gas pipeline imports—the Power of Siberia pipeline from Russia to northeast China—was completed in March 2019 and is expected to begin deliveries in December 2019.

China's coal imports are driven less by insufficient domestic production than the geographical mismatch between coal supply bases in northern China and demand centers in eastern and southern China that lead to high transport costs. In 2017, China imported coal predominantly from Australia, Indonesia, Mongolia, and Russia while over 80% of China's coal exports were to South Korea and Japan. In 2018, net coal imports, primarily from Australia, Indonesia, and Mongolia, accounted for just 6% of national coal consumption, but the supplies of lower cost Australian and Indonesian coal are important to satisfy coal demand in southern China, particularly in Guangdong.

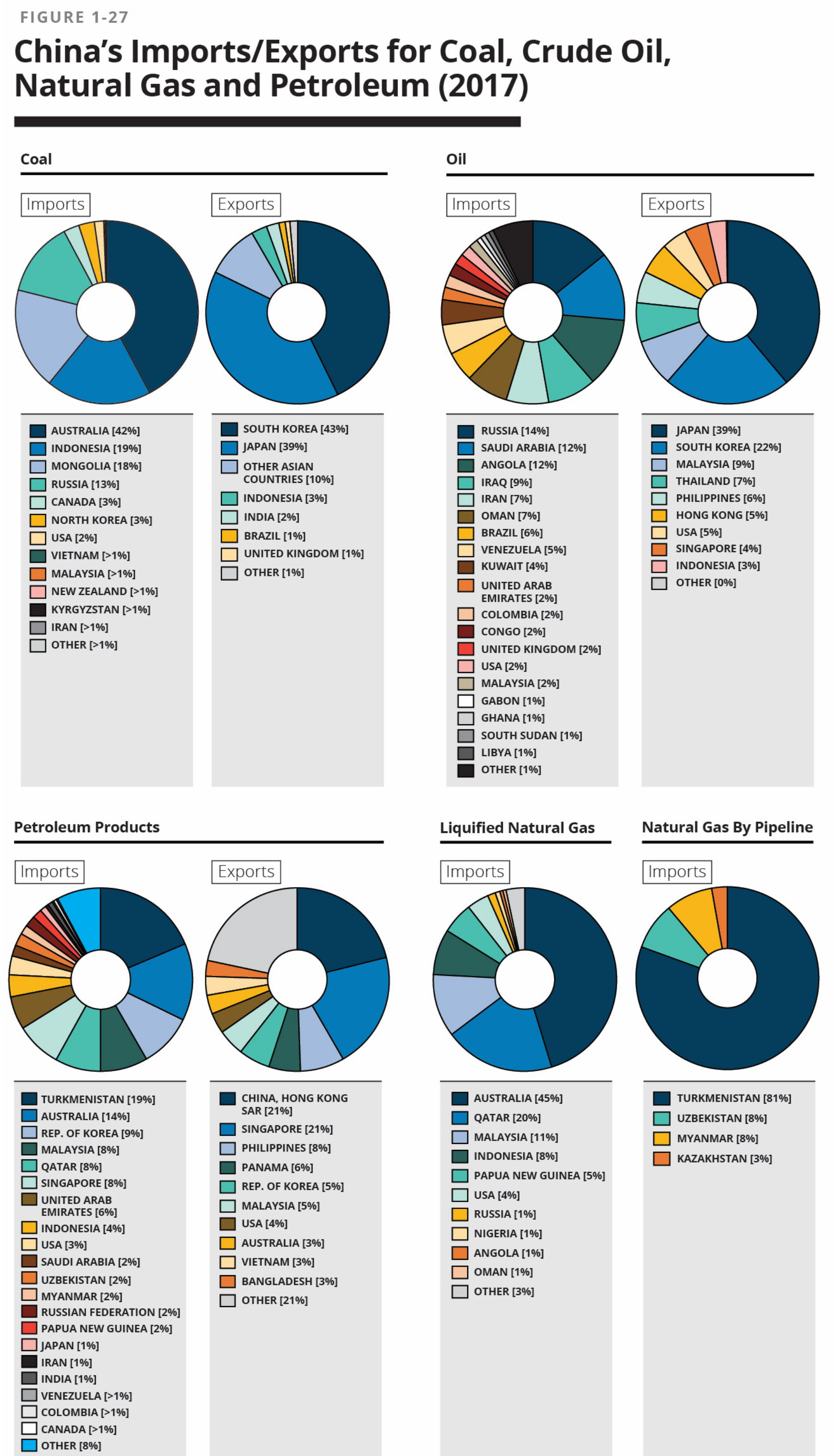


Figure 1-27. China's Imports and Exports of Crude Oil, Petroleum Products, Natural Gas, and Coal (2017)
Source: UN Comtrade; China Customs, 2019.

Table 1-5. China's Imports and Exports of Crude Oil, Natural Gas, and Coal
Source: UN Comtrade; China Customs, 2019.

Country	Crude Oil Imports (Mt)	Crude Oil Exports (Mt)
Russia	59.5	
Saudi Arabia	52.2	
Angola	50.4	
Iraq	36.8	
Iran	31.2	
Japan		1.90
South Korea		1.09
Malaysia		0.42
Thailand		0.33
Philippines		0.28
Other	189.4	0.85
Total 2017	419.5	4.86
Total 2018	461.9	2.63

Country	Natural Gas Imports - Pipeline (bcm)	Liquefied Natural Gas Imports (Mt)
Turkmenistan	34.43	
Uzbekistan	3.64	
Myanmar	3.53	
Kazakhstan	1.14	
Australia		17.27
Qatar		7.48
Malaysia		4.21
Indonesia		3.07
Papua New Guinea		2.10
Other		3.97
Total 2017	42.7	38.09
Total 2018	51.4	53.78

Country	Coal Imports (Mt)	Coal Exports (Mt)
Australia	79.7	
Indonesia	35.3	0.22
Mongolia	33.6	
Russia	25.3	
Canada	5.3	
South Korea		3.48
Japan		3.18
Other Asian Countries		0.77
India		0.17
Other	9.0	0.27
Total 2017	188.1	8.08
Total 2018	246.1	7.87

Energy-Related CO_2 Emissions Trends

China's energy-related carbon dioxide (CO_2) emissions have been increasing continuously since 1980, with the most rapid increases experienced in the 2002-2006 period (Figure 1-28). In recent years, China's total CO_2 emissions dropped by 0.1% in 2015 and 0.6% in 2016 compared to previous years. However, the most recent data show that China's energy-related CO_2 emissions increasing again. Total CO_2 emissions increased by 2% from 2016 to 2017 and by 3% from 2017 to 2018. This increase was the result of a slight (1%) increase in coal use, a 7% increase in petroleum use, and an 18% increase in the use of natural gas between 2017 and 2018. Analysis indicates that it is likely that China's energy-related CO_2 emissions will continue to increase in 2019 (Myllyvirta, 2019).

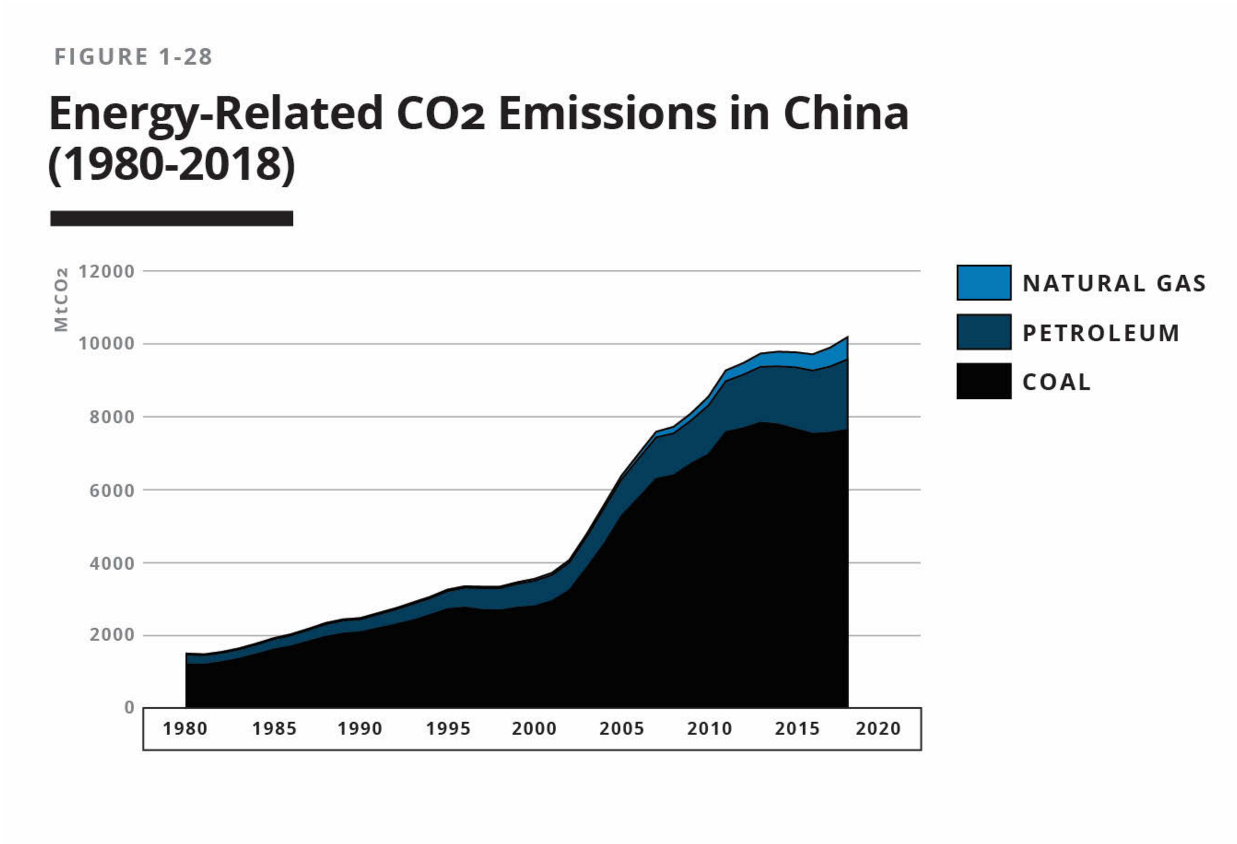


Figure 1-28. China's Energy-Related CO_2 Emissions by Fuel (1980-2018)
Source: NBS, various years (b); IPCC, 2006.
Note: Energy data from NBS are converted to CO_2 emissions using IPCC emissions factors.

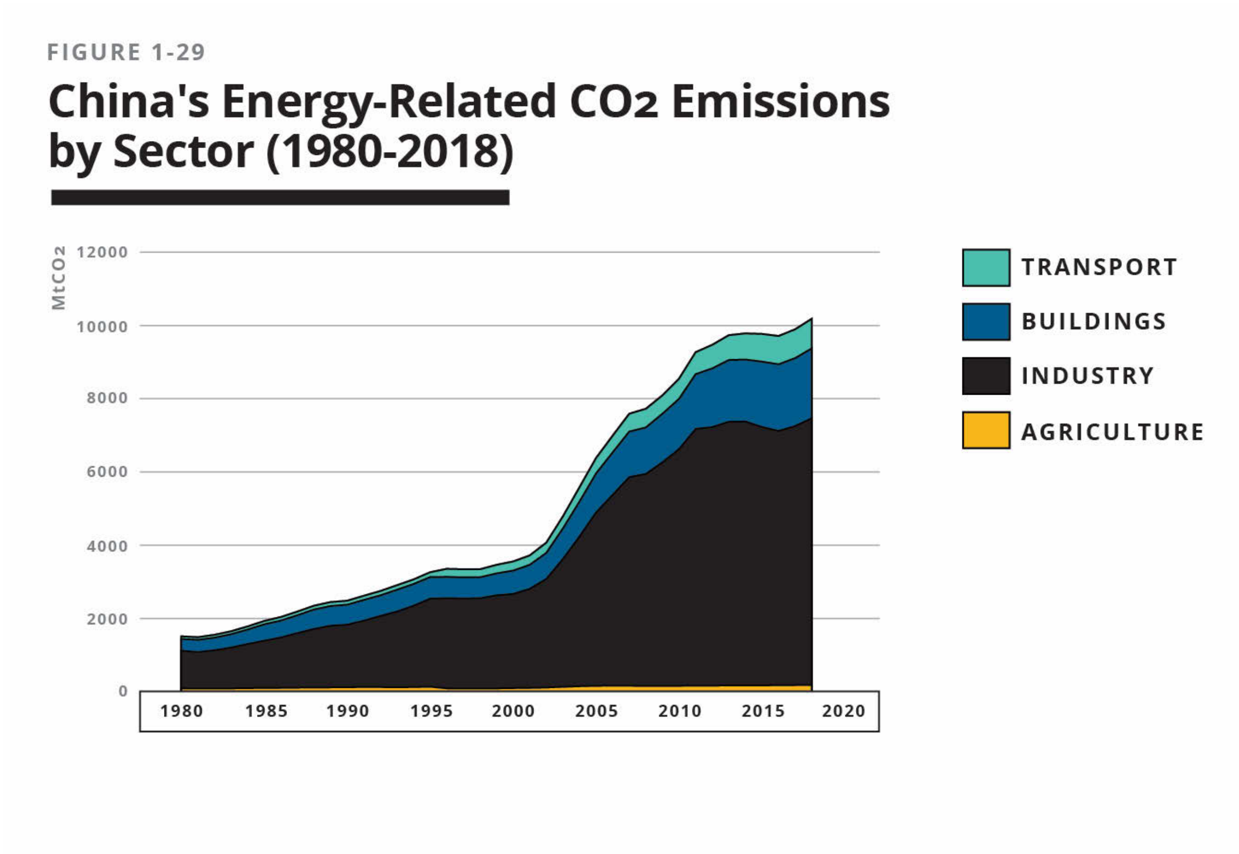


Figure 1-29. China's Energy-Related CO_2 Emissions by Sector (1980-2018)
Source: NBS, various years (b); IPCC, 2006.
Notes: Energy data from NBS are converted to CO_2 emissions using IPCC emissions factors. Industrial sector emissions also include emissions from the construction sector. Sectoral emissions are estimated for 2018 based on 2017 sectoral shares and calculated total emissions based on fuel consumption in 2018.

Figure 1-29 shows that the industrial sector is the largest contributor to China's energy-related CO_2 emissions. Industry accounted for about 70%-75% of China's total CO_2 emissions between 1980 and 2018. The share of industry's contribution declined slightly from 76% in 2010-2011 to 71% in 2018 while the growth rate of China's total CO_2 emissions dropped from 9% per year between 2000 and 2010 to 4% per year between 2010 and 2018. The industrial sector also contributed the most when China's total CO_2 emissions decreased in 2015 and 2016. In 2018, the buildings sector, including residential, commercial, and public buildings, represented around 20% of China's total emissions, with another 8% of emissions coming from the transport sector.

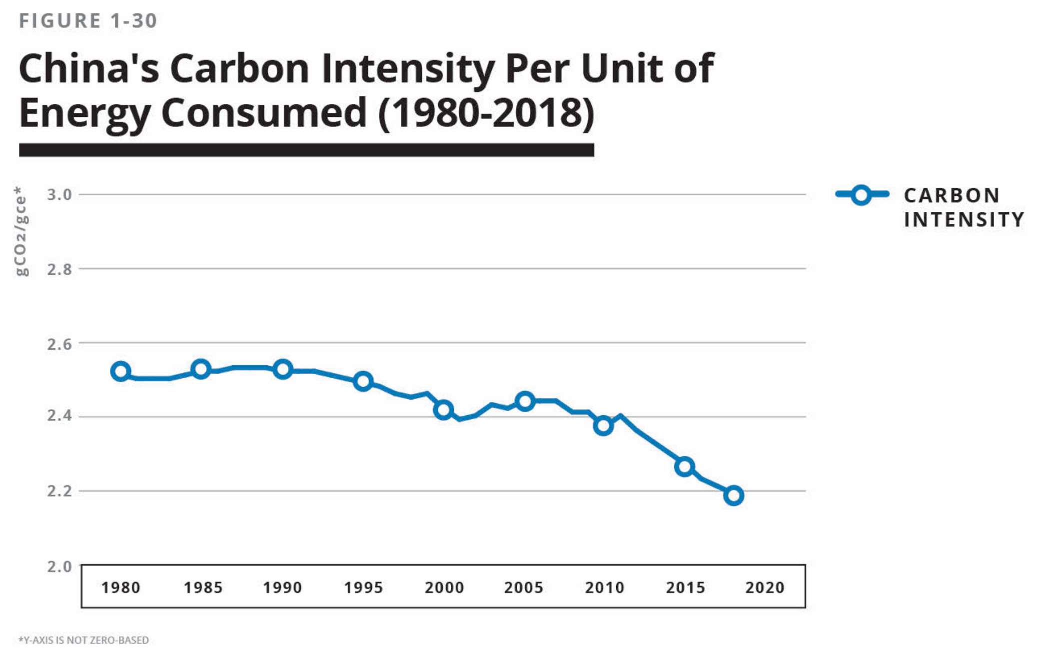


Figure 1-30. China's CO_2 Emissions per Unit of Energy Consumed (1980-2018)
Source: NBS, various years (b); IPCC, 2006.
Note: Energy data from NBS are converted to CO_2 emissions using IPCC emissions factors. Y-axis is not zero-based.

Figure 1-30 shows that China's carbon intensity – defined as CO_2 emissions per unit of energy consumed - was flat between 1980 and 1995, and then began to decrease slowly between 1996 and 2010, at a rate of -0.3% per year. In the last eight years, China's power sector has started to decarbonize with Chinese government support for renewable energy and nuclear power, and as a result the carbon intensity of China's energy consumption has declined faster, decreasing 1% per year from 2011 to 2018.

With its heavy reliance on fossil fuels – especially coal - in its energy mix, China's overall CO_2 emissions per unit of primary energy consumption in 2018 was the highest among the regions and selected countries shown in Figure 1-31. Japan's energy supply is also highly CO_2 intensive largely due to the closure of nuclear plants after the Fukushima nuclear accident in 2011, such that non-fossil electricity only accounted for around 5% of Japan's total primary energy supply in 2016. The CO_2 intensity of the total primary energy supply in the U.S. is lower than that of China and Japan, mostly due to its relatively higher shares of renewables and nuclear power.

While China's total primary energy use per capita is one-third that of the U.S. and half that of OECD countries, China's heavy reliance on fossil fuels means that its energy-related CO_2 emissions per capita are not as low (Figure 1-32). In 2016, the energy-related CO_2 emissions per capita in China were about 44% of the level in the U.S. and 73% of the level in OECD countries. China's CO_2 emissions per capita are 50% higher than the world average and four times higher than the average level in non-OECD Asia countries.

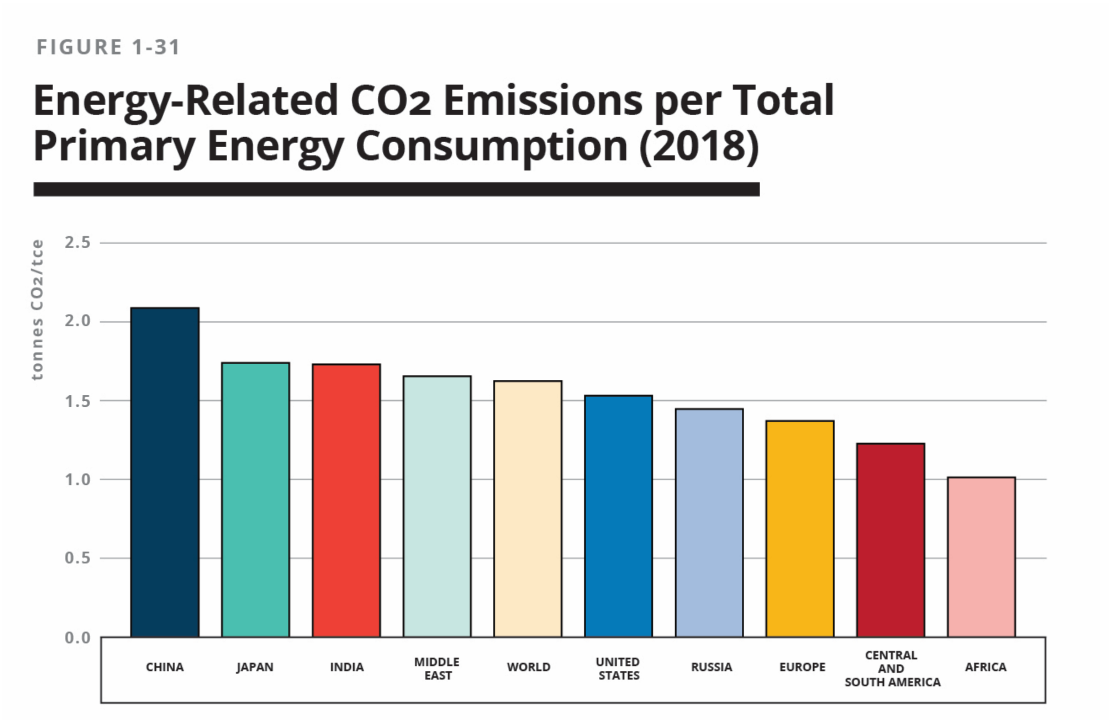


Figure 1-31. China's Energy-Related CO_2 Emissions per Total Primary Energy Consumption, Selected Regions and Countries (2018)

Source: IEA, 2019c. Based on WEO2019 data. All rights reserved.

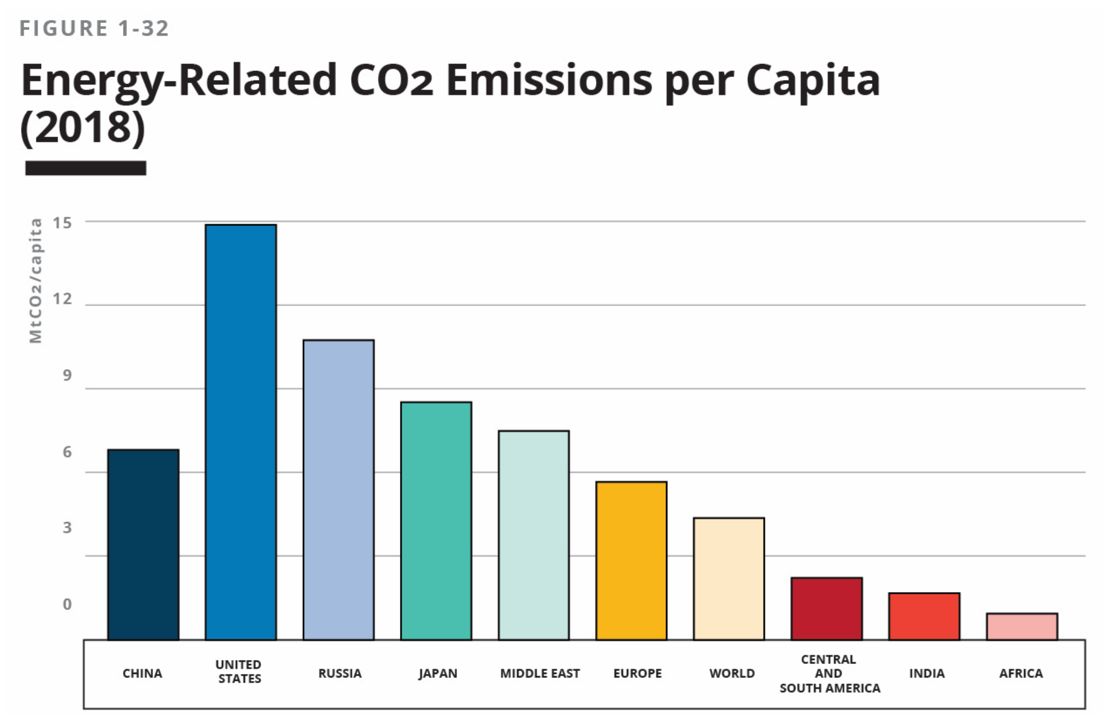


Figure 1-32. China's Energy-Related CO_2 Emissions per Capita, Selected Regions and Countries (2018)

Source: IEA, 2019c. Based on WEO2019 data. All rights reserved.

Chapter 2: China's Key Energy Targets, Policies, and Programs

Introduction

As a socialist market economy, China regularly establishes targets in its Five-Year Plans (FYPs) and other forward-looking reports that include goals for all sorts of measurable outcomes related to the country's economy, development, population, energy, and environment among others. Key among these are China's energy targets, which define its goals for energy supply, energy use, and energy conservation.

China's first energy intensity reduction goal – to decrease energy use per unit of gross domestic product (GDP) by 20% by 2010 over 2005 levels – was introduced during the 11th FYP period (2006-2010). This was followed five years later by the introduction of the country's first carbon dioxide (CO_2) emission intensity reduction goal to decrease CO_2 emissions per unit of GDP by 17% by 2015 over 2010 levels – during the 12th FYP period (2011-2015) to complement the energy intensity goal of 16%.

During China's 13th FYP period (2016-2020), new energy intensity and CO_2 emission intensity reduction targets of 15% and 18%, respectively, were established for 2020 along with a goal of having approximately 15% of total primary energy from non-fossil sources. During this period, China's leaders introduced the concept of "ecological civilization," which includes six principles: resource conservation, resource protection, innovation, green development, ecological quality for the people, and active participation in international collaboration on climate change. China's ecological progress will be monitored via an environmental governance system (环境治理体系) that is being created by the National Development and Reform Commission (NDRC), the Ministry of Industry and Information Technology (MIIT), and the Ministry of Ecology and Environment (MEE) to move beyond end-of-pipe control of emissions (MEE, 2017).

In 2018, President Xi Jinping specifically called for "cultivating and strengthening energy conservation and environmental protection industries, cleaner production industries, and clean energy industries, promoting comprehensive resource conservation and recycling, and realizing the circulation of production systems and living systems." He further advocated for "a simple and modest, green and low-carbon lifestyle, against extravagance and waste and unreasonable consumption" (China Government Website, 2018a).

Despite China's many targets and other efforts, it is now the world's largest emitter of energy-related CO_2, having surpassed the U.S. in 2006 (PBL Netherlands Environmental Assessment Agency, 2007), and is the world's largest primary energy consumer, having surpassed the U.S. in 2010 (Institute for Energy Research, 2010; U.S. EIA, 2015).

This Chapter describes and then evaluates the progress that China has made to date on key national-level energy and energy-related goals and targets. This is then followed by descriptions and progress-to-date of 42 energy-related policies and programs that have been established to assist in the realization of China's overall goals and targets.

National-Level Energy and Energy-Related Targets

- ***Overall, China is on-track to achieve most of its 2020 and 2030 energy and energy-related CO_2 emissions goals.***
- ***China appears to be on track to meet all of its key 13th Five Year Plan 2020 energy and CO_2 emissions goals, except increasing the services sector share of value added.***
- ***China is steadily making progress on both the non-fossil share and CO_2 emissions intensity goals.***
- ***China's energy-related CO_2 emissions continue to grow, but will need to peak and begin to decline in the next decade if China is going to realize a peak in CO_2 emissions by 2030 or earlier.***

China's current energy and energy-related CO_2 emissions goals are set out in key documents issued by the Chinese government, including the *13th Five Year Plan for Economic and Social Development of the People's Republic of China* (13th FYP) covering 2016-2020, the *Energy Supply and Consumption Revolution Strategy (2016-2030),* and the Nationally Determined Contributions (NDCs) for the Paris Agreement focused on 2030. These targets and goals are administered by various government agencies, especially NDRC, MEE, the National Energy Administration, the Ministry of Science and Technology (MOST), the Ministry of Industry and Information Technology (MIIT), the Ministry of Finance (MOF), the Ministry of Housing and Urban-Rural Development (MoHURD), the Ministry of Natural Resources, and the Ministry of Water Resources (see Figure 2-1).

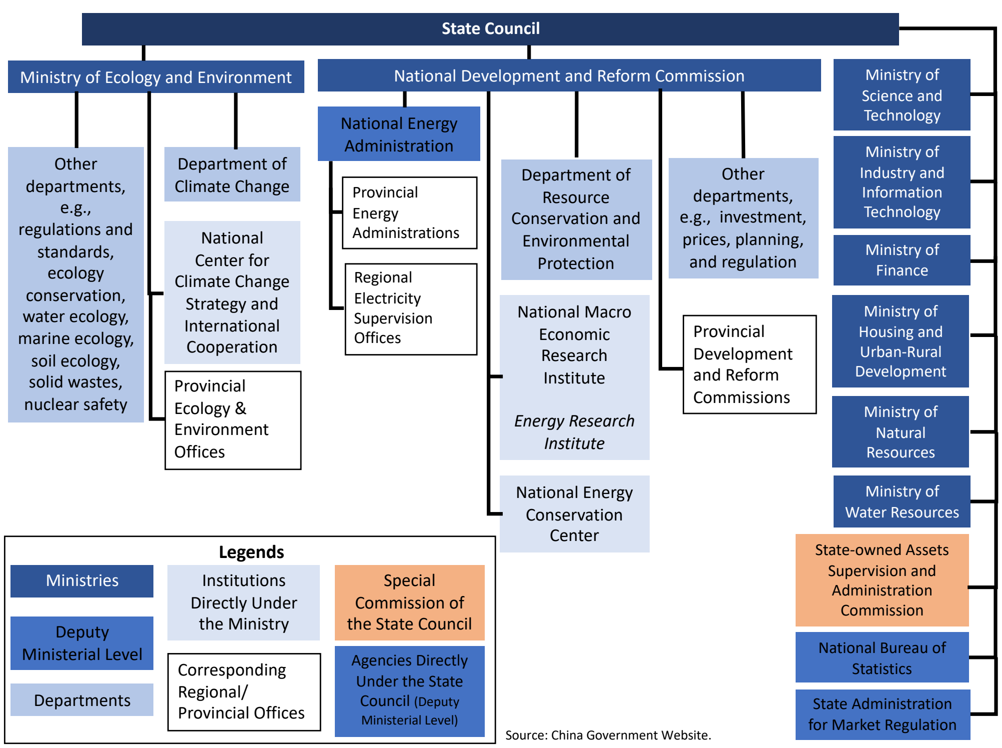


Figure 2-1. Key Chinese Government Offices Responsible for Energy and Energy-Related Emissions Goals.

Table 2-1 provides a summary of China's 2018 progress in achieving key energy and energy-related CO_2 emissions targets. ***Overall, China is on-track to achieve most of its 2020 and 2030 energy and energy-related CO_2 emissions goals.***

Table 2-1. Tracking China's Achievement of Key Energy and Energy-Related Emissions Goals: 2018 Progress, 2020 Goals, and 2030 Goals

	2018 Actual	2020 Goals	2030 Goals	Target Source
Energy intensity reduction (energy/GDP)	12% below 2015	15% below 2015		13th Five Year Plan
Carbon intensity reduction (CO_2/GDP)	14% below 2015	18% below 2015		13th Five Year Plan
Hydropower capacity	352.3 GW	380 GW		13th Five Year Plan
Wind power capacity	184.3 GW	210 GW		13th Five Year Plan
Nuclear power capacity	44.7 GW	58 GW		13th Five Year Plan
Solar power capacity	174.6 GW	110 GW**		13th Five Year Plan
Biomass power capacity	N/A	15 GW		13th Five Year Plan
Services sector value added (% of GDP)	52.2%	56		13th Five Year Plan
Share of coal in primary energy use	59%	<58%		13th Five Year Plan
Total coal consumption cap (Mtce)	2740	4,100		13th Five Year Plan
Primary energy consumption cap (Mtce)	4640 (prelim.)	5,000	6,000	13th Five Year Plan; Energy Revolution Strategy
Share of natural gas in primary energy use	8%	10%	> 15%	13th Five Year Plan; Energy Revolution Strategy
Share of non-fossil energy in primary energy use*	14.3%	~15%	> 20% (~20%)	13th Five Year Plan; Energy Revolution Strategy (Paris Agreement NDC)
Share of non-fossil power generation (% of total generation)	30.9%		> 50%	Energy Revolution Strategy
Carbon intensity reduction 2005 base year (CO_2/GDP)	47%		60%-65%	Paris Agreement NDC
Peaking of energy-related CO_2	still increasing		by 2030 or earlier	Paris Agreement NDC

Sources: Liu, L., 2019, NDRC and NEA, 2016; PRC, 2016; UNFCCC, 2018.
* The energy value of primary electricity (e.g., renewables, nuclear) was converted using China's own Power Plant Coal Consumption method in which electricity sources are converted to standard units based on the average heat rate of Chinese coal-fired power plants each year. For a comparison of China's electricity conversion method to those used internationally, see Lewis et al., 2015.
** including 5 GW concentrated solar power

13th Five Year Plan, 2016-2020

The *13th Five Year Plan for Economic and Social Development of the People's Republic of China* (13th FYP), covering the period 2016 to 2020, is a comprehensive document that provides overall guidance related to China's development including economic, social, cultural, environmental, educational, and other goals and aspirations (PRC, 2016).

Focusing on environmental development goals, the 13th FYP provides the following major objectives:

> "Achieve an overall improvement in the quality of the environment and ecosystems. Our modes of production and ways of life will become more eco-friendly and low-carbon. We will extract and use energy and resources with much greater efficiency. Aggregate energy

> and water consumption, the total amount of land used for construction, and aggregate carbon emissions will be effectively controlled, and aggregate emissions of major pollutants will be significantly reduced."

Focusing on energy-related goals, the 13th FYP promises:

> "We will move ahead with the revolution in energy consumption. We will promote society-wide energy conservation, make comprehensive efforts to promote energy conservation in industry, construction, transportation, public institutions, and other areas, and launch projects to upgrade boilers, furnaces, lighting products, and electric motors and recover waste heat for household heating. We will develop and spur the adoption of energy-conserving technologies and products and demonstrate the application of major energy-conserving technologies."

The 13th FYP prescribes a number of targets to be reached by 2020 including goals related to GDP, total primary energy consumption, and the share of services sector value added which is used to measure China's progress moving away from the energy-intensive industrial sector to services which consume significantly lower energy per unit of value added. In addition, the 13th FYP outlines energy and environmental goals such as the share of non-fossil energy sources in total primary energy and the reduction in energy consumption and CO_2 emissions per unit of GDP (Table 2-1). The 13th FYP goal for 2020 GDP is >92.7 trillion RMB (13.5 trillion US$); in 2018 China's GDP was 83.3 trillion RMB (12.1 trillion US$), on pace to meet the 2020 GDP goal.[16]

After the release of the 13th FYP, an energy development plan under the 13th FYP was announced (NDRC, 2016a). This plan established several key goals for 2020, including limiting China's total energy consumption to under 5 billion tonnes of coal equivalent (Btce) and capping the total coal consumption within 4.1 Btce by 2020. The plan also calls for increasing the share of non-fossil energy consumption to 15% and above by 2020 while reducing the share of coal in total energy use to below 58%.

China appears to be on track to meet all of its key 13th FYP 2020 energy and CO_2 emissions goals, except the services sector share of value added (Figure 2-2), which was 52.2% in 2018, just slightly behind the value needed to keep on a steady pace to the goal of 56%. Note, however, that the increase in the services (tertiary) sector value added has occurred because of the decrease in the primary sector, not because of a decrease in the share of the industry (secondary) sector, which represented 41% of the share of value added in China's GDP in both 1990 and 2018.

[16] Converted using https://www1.oanda.com/currency/converter/ on July 1, 2019.

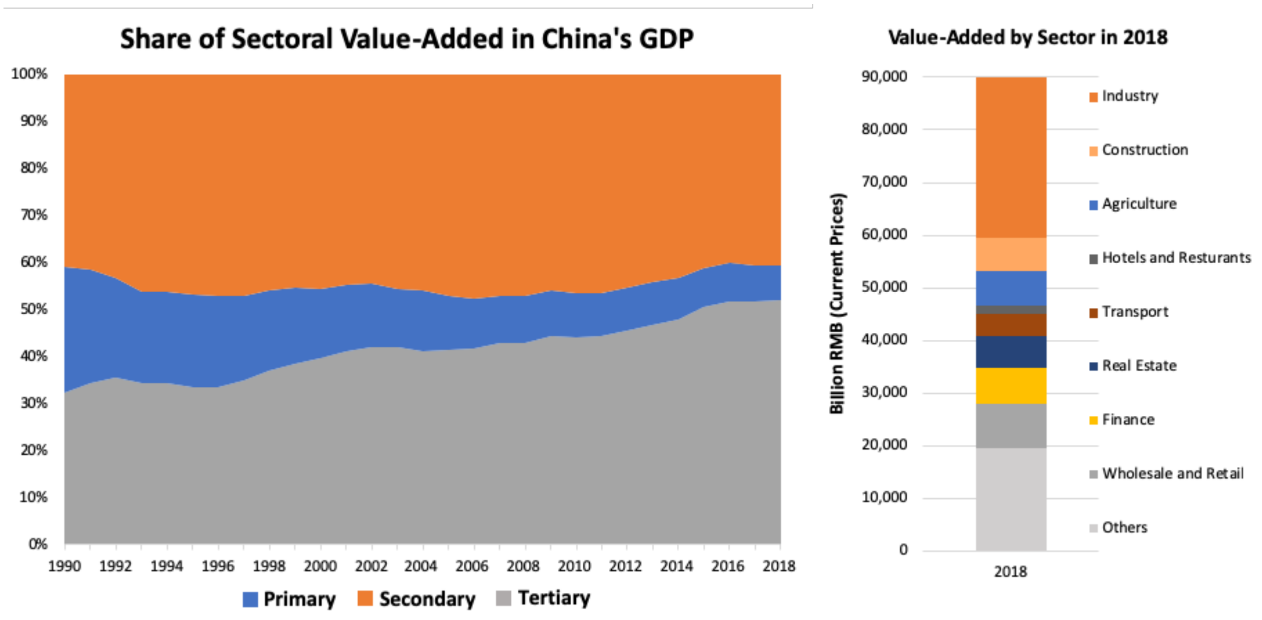


Figure 2-2. Share of Sectoral Value Added in China's GDP (1990-2018) and Value-Added by Sector, 2018.
Sources: NBS, various years; NBS, 2019c; NBS, 2013.
Notes: Primary = agriculture, forestry, farming, and fishing; Secondary = mining, manufacturing, construction, power, heat, natural gas, and water production and supply; Tertiary = services

Regarding installed capacity for renewable electricity sources, China installed 175 GW of solar by 2018, exceeding the 2020 goal of 110 GW. China is on track to meet or exceed the hydropower capacity goal (352 GW installed; 2020 goal of 380 GW), wind power capacity goal (184 GW installed; 2020 goal of 210 GW), and the nuclear power capacity goal (45 GW installed; 2020 goals of 58 GW).

Energy Supply and Consumption Revolution Strategy, 2016-2030

In April 2017, China released the *Energy Supply and Consumption Revolution Strategy (2016-2030)* that reiterates a number of its 2020 national energy goals and also sets additional goals for 2030 (NDRC and NEA, 2016). The new 2030 goals are to cap China's absolute primary energy consumption at or below 6,000 Mtce, increase the share of non-fossil energy in total primary energy to 20%, increase the share of natural gas in total primary energy consumption to 15%, and strive to have 50% of total power generation from non-fossil sources. In addition, this strategy sets the following goals to be achieved by 2030: China's economic energy intensity to reach global average levels, key industrial products' energy efficiency levels to reach global advanced levels, incremental energy demand to be met primarily by clean energy, and the share of ultra-low polluting coal-fired power plants to be more than 80% of the fleet.

Paris Agreement Nationally Determined Contributions (NDCs)

In September 2016, China ratified the *Paris Agreement,* which commits participating parties to "holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels" (UN, 2018a). China's specific *Paris Agreement* commitments, as conveyed through its

Nationally Determined Contributions (NDCs), include peaking CO_2 emissions around 2030 and making best efforts to peak early as well as increasing the share of non-fossil fuels in primary energy consumption to around 20% by 2030. China's 2030 NDCs also include lowering CO_2 emissions per unit of GDP by 60% to 65% from the 2005 level (UNFCCC, 2018).

China is steadily making progress on both the non-fossil share and CO_2 emissions intensity goals. In 2018, the share of non-fossil fuels in primary energy consumption – using China's power plant coal consumption conversion methodology – was 13.8%, which is on pace to reach the 2020 goal of 15%. China's energy-related CO_2 emissions per unit of GDP relative to 2005 have dropped an estimated 47% as of the end of 2018, which is on track to meet the goal of reducing CO_2 emissions intensity by 60%-65% by 2030.

As of the end of 2018, China's energy-related CO_2 emissions have continued to grow, predominately due to increased combustion of fossil fuels during the 2017 to 2018 period (see Table 2-2) and are currently estimated to have just surpassed 10 $GtCO_2$, a 4% increase over the 2015 value. ***This recent growth in energy-related CO_2 emissions will need to peak and begin to decline in the next decade if China is going to realize a peak in CO_2 emissions by 2030 or earlier.***

Table 2-2. China's Primary Energy and Energy-Related CO_2 Emissions, 2015-2018.

	2015	2016	2017	2018*
Coal (Mtce)	2739	2703	2711	2740
Petroleum (Mtce)	787	798	844	899
Natural gas (Mtce)	254	279	320	370
Primary electricity (Mtce)**	520	580	614	620
Total primary energy consumption (Mtce)	4,299	4360	4490	4,620
Energy-related CO_2 emissions ($MtCO_2$)	9,747	9,714	9,906	~10,000

Sources: NBS, 2019c; NBS, various years; IPCC, 2006***

Notes: *estimated

**The energy value of primary electricity (e.g., renewables, nuclear) was converted using China's own Power Plant Coal Consumption method in which electricity sources are converted to standard units based on the average heat rate of Chinese coal-fired power plants each year. For a comparison of China's electricity conversion method to those used internationally, see Lewis et al., 2015.

***China's reported energy consumption converted to CO_2 emissions using the IPCC's 2006 CO_2 emissions factors.

Key Energy-Related Policies and Programs

To achieve its myriad domestic and international energy-related goals, China has established many policies and programs at the national, subnational, and sectoral levels. Some of these are relatively new while others are continuations of long-standing efforts. Some are just now in the pilot stage while others started as pilots and are now larger efforts.

This section provides a brief description of 42 selected policies and programs currently in place in China focused on energy and related emissions, building on the China Energy Group's 30+ years of policy and program development, implementation, and analysis in China and augmented by information provided through publicly-available documents and 18 interviews with research staff and policymakers in China. This section also categorizes the 42 selected policies and programs by their coverage using the following categories:

- National – broad in scope and apply to all of China
- Subnational – only active in specific locations in China
- Industry – manufacturing activities
- Buildings – commercial (including government/public) and residential buildings, covers urban and rural buildings
- Appliances and equipment – energy-consuming components of buildings
- Transportation – all forms of transportation, except international air flights
- Power – all types of electricity consumption and production

This section further categorizes the 42 selected policies and programs by type using the following categories, based on the typology presented by the Intergovernmental Panel on Climate Change Working Group III in its *Fifth Assessment Report* (IPCC, 2014) and informed by the International Energy Agency (IEA, 2020), Gallagher and Xuan (2018), and Climate Policy Initiative (2013):

- Regulatory/Administrative: policies or programs that establish a mandatory rule, targets, goals, minimum performance standards, or energy use limits with penalties in case of non-compliance.
- Economic: policies or programs that include taxes (or tax credit/reduction), subsidies (or subsidy removal), research and development support, or establish rules for new markets (e.g. cap-and-trade; emissions trading).
- Informational: policies or programs such as labels, certificates, and data disclosure designed to provide relevant information to inform consumption and production decisions.
- Voluntary: policies or programs that solicit voluntary actions by enterprises or other actors separate from regulatory requirements, often undertaken to provide flexibility in compliance methods.
- Motivational: policies or programs that provide enterprises or other actors with non-monetary incentives to participate and achieve specific goals or targets.

Detailed descriptions of the 42 energy-related policies and programs currently in effect in China that are covered in this Chapter are provided online at https://china.lbl.gov/china-energy-outlook.

Key Energy-Related Policies and Programs: National and Subnational

The six national and three subnational policies and programs covered here are quite comprehensive, aiming to reduce energy intensity and cap energy use across China's provinces, to establish energy use quotas and trading, to set energy efficiency standards for nearly 100 energy-consuming products, to identify and acknowledge best energy-efficiency performers, to start emissions trading, to meet air pollution reduction targets, and to establish low carbon cities across the country. Table 2-3 provides an overview of the coverage of these efforts as well as their current status. Overall, these national and subnational policies and programs represent important efforts to control energy use and related emissions using the full range of possible policy approaches.

Two of the four regulatory/administrative programs - the 100 Energy Efficiency Standards Promotion Project and the regulatory air quality goals of the Winning the Battle for a Blue Sky program - have been fully implemented and are either on track or have already met the goals of these programs. Most provinces are on track to meet both the energy consumption cap and the energy intensity targets of the Double Control Program, but some provinces are struggling to meet their total energy consumption target as they try to balance this goal with their economic growth ambitions. The 100-1000-10,000 Program – the successor to the highly-successful Top-1000 and Top-10,000 Programs – has made little progress to date.

Of the three economic programs – the Energy Consumption Quota Trading Program, the National Emissions Trading Program, and Green Financing – only the Green Financing program is progressing rapidly, with significant increases in green credit and green bond issuances in recent years. The other two more market-based economic programs have not moved past the pilot phase, but are slowly gathering experience and making progress toward larger future efforts.

The remaining programs – the Energy Efficiency Top Runner Program, the Low-Carbon Pilot Cities and Provinces Program, and a portion of the 100 Energy Efficiency Standards Promotion Program – have informational, voluntary, and motivational components. A total of 43 voluntary standards on energy–savings measurement, energy management systems, energy use monitoring, and economic operation have been promulgated under the 100 Energy Efficiency Standards Promotion Program. While the Low-Carbon Pilot Cities and Provinces Program has substantial participation and has made significant progress undertaking voluntary energy and GHG inventories, setting targets, preparing low-carbon action plans, and developing local standards and incentives that go beyond national requirements, current efforts under this program seemed to have slowed as the focus shifts to dual control of CO_2 and air pollutants. The Energy Efficiency Top Runner Program has been established through three distinct efforts focused on industrial facilities, appliances, and public institutions, but the program is experiencing weak participation to-date.

Table 2-3. China's Key Energy-Related Policies and Programs: National and Subnational

Policy/Program	Type	Coverage		Current Status
Double Control Program	Regulatory/ Administrative	National	All provinces	Struggling to meet the total energy consumption target
100-1000-10,000 Program	Regulatory/ Administrative	National	Industry, Buildings, Transportation: 100 enterprises (annual energy use of 3 Mtce or higher); 1,000 enterprises (0.5 Mtce or higher), remainder (less than 0.5 Mtce)	Lack of notable progress to date
Energy Consumption Quota Trading Program	Economic	Subnational	Zhejiang, Fujian, Henan, and Sichuan pilots: mostly industry plus thermal power generation	4 provincial pilots ongoing
100 Energy Efficiency Standards Promotion Project	Regulatory/ Administrative; Informational; Voluntary	National	~100 energy-consuming products, energy-savings measurement, energy management systems, energy use monitoring	96 energy efficiency standards established; some implementation issues
Energy Efficiency Top-Runner Program	Informational; Voluntary; Motivational	National	End-use energy consuming products, high energy-consuming industries, and public institutions	Progressing but with weak participation
National Emissions Trading Scheme	Economic	National	All power plants emitting over 26,000 tons of CO_2e per year; is expected to expand to 7 industrial sectors in the future	Trial operation with simulated transactions for the power sector only
Green Finance	Economic	National	Green bonds, green lending, green development funds, green insurance, markets for pollution control rights, local government initiatives, and international cooperation	Some concern about China's broad definition of "green"; significant increases in green credit and green bond issuances in recent years.
Winning the Battle for a Blue Sky	Regulatory/ Administrative	Subnational	Beijing-Tianjin-Hebei and surrounding areas, the Yangtze River Delta, the Fen River and Wei River Plains	On track to meet 2020 goals
Low Carbon Pilot Cities and Provinces	Informational; Voluntary; Motivational	Subnational	84 low-carbon city/province pilots	84 low carbon cities/provinces have set CO_2 peaking goals

Double Control Program

Overall, the Double Control Program is meeting its energy intensity goal, while struggling to meet its energy consumption goal due to the recent growth in both electricity demand and overall energy use in China.

China's *13th Five-Year Plan (FYP)* and *Energy Supply and Consumption Revolution Strategy (2016-2030),* call for control of both total energy consumption and energy intensity (energy use per unit of value-added) (State Council, 2016a). These "Double Control" targets will cap China's absolute primary energy consumption – which was 4.3 Btce in 2015 – at or below 5 Btce and 6 Btce by 2020 and 2030, respectively, and reduce China's energy intensity by 15% from 2015 levels by 2020 (State Council, 2016a). Under this Double Control program, provincial governments are responsible for implementation of absolute energy consumption targets and energy intensity reduction targets that have been allocated to each province. NDRC has been carrying out annual performance examinations and reviews to determine if provinces are meeting their allocated targets (Tian, 2019).

The recent growth in both electricity demand (8.4% between 2017 and 2018) and primary energy use (4% between 2017 and 2018) throughout China is making it difficult for the country to achieve the 2020 energy consumption control target (NBS, 2019c). New provincial projects that drive provincial GDP – but also increase energy use - are being built, leading to further expected increases in primary energy consumption in the last two years of 13th FYP. Four provinces (Shanghai, Zhejiang, Ningxia, and Xinjiang) have already consumed energy significantly greater than they should have at this point in the program. All of the other provinces are on track to consume less energy – and some significantly less energy – than their allocated 2020 Double Control Program energy consumption targets (NBS, 2018b).

Regarding the energy intensity reduction targets, 28 out of 30 provinces are on track to meet their energy intensity reduction goals. Hubei, Guangdong, Chongqing, Sichuan, Guizhou, and Qinghai have already completed *and exceeded* their energy intensity reduction goals. Only Inner Mongolia and Ningxia are not on track, with Ningxia's energy intensity actually increasing by over 20% (NBS, 2018b).

100-1000-10,000 Program

While designed to complement China's Double Control targets, the new 100-1000-10,000 Program has had less impact to date compared with its predecessor Top-1000 and Top-10000 programs due to its slow start.

China's *Key Energy-Consuming 100-1000-10,000 Organizations Action* was launched in November 2017 to play a supporting role in China's achievement of its "Double Control" targets (NDRC, 2017a). As described above, the national "Double Control" targets are allocated to each province; these provincial targets are further allocated to the provincial 100-1000-10,000 program enterprises.

The 100-1000-10,000 Program builds on previous programs implemented during the 11th and 12th FYPs: the Top-1,000 Enterprises Energy Saving Program (Top-1,000 Program) and the Top-10,000 Program, both of which surpassed their energy-savings goals (NDRC, 2006; NDRC, 2011; NDRC, 2015a)

Specific targets for the local 100-1000-10,000 Program enterprises are determined at the subnational level by the county, city, or provincial governments. The 100-1000-10,000 Program includes not only industrial companies, but also key enterprises in buildings, transportation, and public institutions. The program categorized the enterprises into three groups (see Table 2-4). The annual performance evaluations of the 100-1000-10,000 enterprises mainly focus on assessing whether these enterprises have achieved their annual "Double Control" obligation.

Table 2-4. 100-1000-10,000 Program Categories and Supervisory Responsibility Levels

Category	Annual Energy Consumption	Supervisory Responsibility Level
100	3 Mtce and higher	Provincial level government
1000	0.5 – 3 Mtce	Provincial level government
10,000	Below 0.5 Mtce	City and county-level government

As of March 2019, provincial governments were still working on target allocation for 2019 and 2020 among their key energy-consuming enterprises, and NDRC has been urging the provincial governments to accelerate the work on allocating the targets to their local enterprises (NDRC, 2019a). Provincial governments are required to connect their key energy-consuming enterprises to an online energy consumption monitoring system created by NDRC by 2020 (NDRC and SAMR, 2019). Information on program performance at the national level is not available as of May 2019, but as an example of current progress, Hebei Province has developed evaluation indicators and scoring cards to evaluate participating enterprises (Hebei Government, 2019).

Energy Consumption Quota Trading Program

Pilots for allocation and trading of energy use quotas in four provinces, each having different features, started operation in 2018-2019 to support the Double Control Program.

To move away from its iron-fist administrative approach to curbing energy use and related emissions, China has been moving toward a more market-based approach through establishing three separate trading schemes including a carbon cap and trade scheme, a scheme of tradable pollution rights, and this energy consumption quota trading scheme as an important market-based measure for accelerating the development of an "ecological civilization" (China Government Website, 2015).

In March 2016, the State Council proposed in the 13th Five-Year Plan to develop energy consumption quota trading markets to support the achievement of the Double Control Program targets of total energy consumption and energy intensity. The establishment of the energy consumption quota trading system is a new attempt to change the government management mode, leaving more decision-making for enterprises in an effort to promote the efficient allocation of energy resources. It is envisioned that the trading system will help local governments optimize the industrial structure, giving them opportunities to use market tools to allocate energy resources to enterprises more efficiently with better economic returns and improve the quality of regional economic development.

In July 2016, NDRC selected four provinces - Zhejiang, Fujian, Henan, and Sichuan - as trading pilots (NDRC, 2016b). The preliminary research and preparation work of the four pilots has been completed and the provincial pilot implementation plans have been formulated (Tian, 2019). By the end of 2018, the energy consumption quota trading systems began operating in Fujian and Zhejiang provinces (NDRC, 2018a).

100 Energy Efficiency Standards Promotion Project

To date, 96 energy efficiency standards have been established under China's 100 Energy Efficiency Standards Promotion Project covering many products and industries, but implementation has been uneven and there is a lack of harmonization with international standards.

Energy efficiency standards have played a key role in supporting China's energy conservation and emission reduction work since 1988. In 2014, the National Standardization Commission and NDRC jointly launched the "100 Energy Efficiency Standards Promotion Project" to address the problem of narrow coverage of energy consumption limit standards and low stringency of energy efficiency standards (NDRC and NSC, 2012; Xinhua Net, 2014). Since 2015, 96 energy efficiency standards have been released (Table 2-5). These standards provide a scientific basis for national and local governments to eliminate backward production capacity more objectively, support the work in benchmarking and provide the basis for doing the energy-saving responsibility evaluation, improve the energy efficiency level of specific sectors, equip energy-saving monitoring and enforcement agencies with solid information when conducting inspections, and support the establishment of an energy efficiency standardization system.

Table 2-5. 100 Energy Efficiency Standards Promotion Project

Standard Type	Number of Standards
Mandatory energy consumption limit	34
Mandatory product energy efficiency standards for equipment performance	19
Voluntary standards on energy–savings measurement, energy management systems, energy use monitoring, and economic operation	43

Energy efficiency standardization involves a large number of government agencies, fields, and industries but a strong mechanism for coordination and alignment is missing, particularly for voluntary standards. An effective standardization coordination mechanism is therefore important to address the lack of harmonization, including harmonizing its standards with international standards. In addition, voluntary standards implementation is weak. There is no systematic and persistent training, promotion, and supervision related to voluntary energy efficiency standards. Many local government entities, quality inspection departments, and corporate energy managers are not familiar with voluntary energy efficiency standards, creating difficulties in implementation (Yu, 2019).

Energy Efficiency Top-Runner Program

While the Energy Efficiency Top Runners for industry, the public sector, and end-use products have been selected and publicized on a regular basis since 2016, there is a lack of monetary incentives or rewards to motivate Top Runners to continue improving and there are weaknesses in program design and participation.

Drawing on the experience from Japan's Top Runner Program, China initiated its Top-Runner Program to recognize the best performers in energy efficiency in China's industrial facilities, appliances, and public institutions (NDRC, 2014a; State Council, 2012; State Council, 2013a; State Council, 2013b; State Council, 2014). By publishing and recognizing the Top-Runners, the program aims to support and incentivize the best performing enterprises as well as to guide additional enterprises and public institutions to become Top-Runners.

The implementation of China's Energy Efficiency Top-Runner Program covers three areas: high energy-consuming industries, public institutions, and end-use energy consuming products. The three program areas have different scopes, different implementation methods, and different responsible agencies. The implementation of these programs is proceeding with Top-Runners being selected and publicized with plans for the program to expand year-by-year, although some program design issues need to be addressed to increase participation. In addition, the government proposed to develop incentives for rewarding Top-Runners, but there are no substantial financial incentives for the Top-Runners.

National Emissions Trading System

China's long-awaited National Emissions Trading System has started, with only the power sector participating in the first phase from 2017 to 2020 to build and test the various emission trading components, but is behind schedule.

After five years of provincial-level emission trading pilots, China officially launched its nationwide CO_2 emissions trading scheme (ETS) in 2017, starting with the power sector. All power plants emitting over 26,000 tons of CO_2e per year are required to join the inaugural phase of the program, which was originally envisioned to consist of a basic construction period (2018), a market trial operation period (2019), and a period to carry out spot trading of emission allowances (2020) (Forbes, 2017; MEE, 2019a; NCSC, 2016; Xinhua Net, 2017c). However, China is behind on this schedule and just now identifying and signing up the required power plants, with no market trading to date although it is expected that the first trades will happen in 2020.

Upon achieving stable operation, China's ETS is expected to gradually expand to cover seven industrial sub-sectors including petrochemicals, chemical engineering, construction materials, iron and steel, non-ferrous metals, paper, and aviation with enriched trading varieties and diversified trading methods (NDRC, 2016c).

Green Financing

Since 2016, China has experienced rapid development of green financing policy - including green bonds, green lending, green development funds, green insurance, and markets for pollution control rights – and is now a leader internationally in this area despite some questions regarding its broad definition of "green".

Since 2016, China has established, arguably, the most coordinated and comprehensive green financing policy framework in the world (IPEEC, 2016; Columbia University, 2019). Green financing is defined by China as "financial services provided for economic activities that are supportive of environmental improvement, climate change mitigation, and more efficient resource utilization" (Columbia University, 2019).

To support the development of green financing, China's various ministries and commissions have issued a series of policy guidelines related to green bonds, green lending, green development funds, green insurance, markets for pollution control rights, local government initiatives, and international cooperation (CBRC, 2015; Columbia University, 2019; CSRC, 2017; Dai et al., 2016; GCF, 2018; IFC, 2012; Jiang et al., 2018; *PBOC, 2015a; PBOC, 2015b;* PBOC, 2016; *Peng et al., 2018; Wang, 2018*). In addition, in 2017 China's State Council established *Green Finance Reform and Innovation Pilot Areas* in Zhejiang, Jiangxi, Guangdong, Guizhou, and Xinjiang to explore green finance reform and innovation and to develop replicable solutions to scale up green finance nationally (Paulson Institute, 2019; Wang et al., 2017).

China's green credit and green bond issuances have risen steeply in recent years. In 2018, China's green loan balance reached RMB 8 trillion, an increase of 16% against the previous year. China also issued 283 billion RMB in green bonds, making it the second largest national green bond issuer in 2018, behind only the United States (Columbia University, 2019). And while controversies exist with regard to China's broad definition of "green," (i.e., clean coal), the country offers a clear blueprint for greening a national financial system from the top-down. Through its leadership at the 2016 G20 Summit, and support for the 2016 *G20 Leaders Communiqué*, China is also responsible for building consensus within the international community to jointly promote the development of green finance globally to advance environmentally sustainable economic growth (UNEP, 2016; Wang et al., 2017; Chong, 2019).

Winning the Battle for a Blue Sky

The air pollution reduction targets set out in China's Winning the Battle for a Blue Sky program have either been met or are on track to be achieved by 2020 in the Beijing-Tianjin-Hebei and surrounding areas, the Yangtze River Delta, and the Fen River and Wei River Plains.

In an effort to significantly reduce the total amount of air pollutants, support the reduction of greenhouse gas (GHG) emissions, continue reducing the concentration of particulate matter (PM) 2.5, significantly reduce the number of days of heavy pollution, and improve air quality, China's State Council announced a *Three-Year Plan on Defending the Blue Sky* in June 2018 (China Government Website, 2018b) which specifically focuses on Beijing-Tianjin-Hebei and surrounding areas, the Yangtze River Delta, and the Fen River and Wei River Plains.

A number of policies have been put in place to support the *Three-Year Plan on Defending the Blue Sky*, including adjusting industrial structure and promoting green development, promoting fuel switching to electricity, natural gas, and clean (low-ash, low-water content) coal in the winter heating season in Northern China, accelerating the elimination of small coal-fired boilers, lowering the share of road transport and increasing the share of rail freight, cracking-down on excessive emissions of diesel-powered trucks, continuing the ultra-low emission retrofits in coal-fired power plants, starting the ultra-low emission retrofits in the iron and steel industry (MEE, 2019b), and strengthening the management of volatile organic compounds (VOCs) in key industries. The Plan sets out specific reduction goals for SO_2, NO_X, $PM_{2.5}$, as well as other pollutants. As of 2018, initial reports show that the goals have either been met or are on track to be met during the 13th Five Year Plan period (Kou and Sun, 2019; Liu, Y., 2019; Xinhau Net, 2019a).

Low-Carbon Pilot Cities and Provinces

China's Low Carbon Pilot Cities and Provinces have announced CO_2 peaking targets. In support of these targets, they are conducting energy and GHG emissions inventories, preparing action plans, and establishing local standards and incentives.

NDRC's low carbon development pilot program – launched in 2010 – was established to motivate and provide support to Chinese cities in conducting energy and GHG inventories, setting targets, preparing low-carbon action plans, and developing local standards and incentives that go beyond national requirements (Khanna et al., 2014).

Some cities have explicitly announced their CO_2 emissions peaking year goals in provincial-level 13th Five-Year Plan for GHG emissions, including Beijing (2020 or earlier), Tianjin (around 2025), Yunnan Province (around 2025), Shandong Province (around 2027), or in the city overall plan (i.e. Shanghai). By the end of 2017, 80 low-carbon pilot cities and 4 provinces had established CO_2 peaking year goals (NCSC, 2018). Table 2-6 shows the CO_2 peaking year goals of these cities and provinces where 4 cities plan to peak before 2020, 12 cities plan to peak in 2020, 15 cities plan to peak between 2021 and 2024, 30 cities and 1 province plan to peak in 2025, 11 cities plan to peak between 2026 and 2029, and 8 cities and 3 provinces plan to peak in 2030.

In addition, over 400 low-carbon community pilots have also been implemented across 22 provinces since 2017. Most of those low-carbon community pilots developed implementation plans; some of them (e.g. Beijing, Shanghai, Hebei, Jiangxi, Hubei, Guangxi, and Shaanxi) established evaluation indicators or guidelines for low-carbon community pilot development. China has also initiated climate adaptive city pilots in 28 cities in 2017 (NDRC, 2017d).

Table 2-6. Low Carbon Cites and Provinces with CO_2 Emission Peak Year Targets

Peak Year	City or PROVINCE
2017	Yantai
2018	Ningbo
2019	Dunhuang, Wenzhou
2020	Beijing, Guangzhou, Hangzhou, Huangshan, Jinhua, Jiyuan, Nanping, Qingdao, Suzhou, Wuzhong, Xiamen*, Zhenjiang
2021	Yining
2022	Nanjing, Quzhou, Shenzhen, Wuhan
2023	Changyang Tujia, Changzhou, Ganzhou, Ji'an, Jiaxing, Jingdezhen*
2024	Great Khingan*, Hefei, Lhasa, Xunke
2025	Aral Shehri, Changji, Changsha, Chaoyang, Chengdu, Dalian, Guiyang, Hetian, Huai'an*, Huaibei, Jilin, Jinan, Jinchang, Jincheng, Lanzhou, Nanchang*, Qinhuangdao*, Qiongzhong Li and Miao, Sanya, Shanghai, Shijiazhuang*, Simao, Tianjin, Weifang, Wuhai, Xining, Xuancheng, Yinchuan, YUNNAN, Zhongshan, Zhuzhou
2026	Fuzhou, Liuzhou
2027	Chenzhou, Gongqingcheng, Sanming, Shenyang
2028	Ankang, Hulun Buir*, Xiangtan, Yuxi
2029	Yan'an
2030	Chizhou, Chongqing, GUANGDONG*, Guangyuan, Guilin, HAINAN, Kunming*, Liu'an, SICHUAN, Urumchi, Zunyi

Source: NDRC, 2017b. Note: Names in all CAPITAL LETTERS are provinces.* Cities or provinces that have calculated their peak years, but did not published their targets by the end of 2017, the last time the National Center for Climate Change Strategy and International Cooperation (NCSC) surveyed the low-carbon pilots.
A list of the 45 new pilot cities, including their CO_2 peaking target year, is available (in Chinese) at NDRC, 2017c.

Industrial Sector

China's industrial sector[17] is the largest end-use sector in China in terms of primary energy use, consuming 70% of China's total primary energy in 2018. China's industrial sector primary energy consumption is larger than the ***total*** national energy consumption of every country worldwide, except the U.S. (BP, 2019b). China's industrial sector is responsible for an even larger share of the country's total energy-related CO_2 emissions, emitting 71.5% in 2018 down slightly from the high of 75.6% in 2010 and 2011.

Two overall intensity reduction targets – one for energy intensity and the other for CO_2 emissions intensity – were established for China's industrial sector by the State Council with a number of key central government agencies, e.g., NDRC and MIIT (see Table 2-7). By the end of 2018, China's energy use per unit of industrial value-added declined by 13.6%, making steady progress toward the 2020 goal of 18%. China has not reported its progress toward the 2020 goal of a 22% reduction in CO_2 emissions per unit of industrial value added, but it is estimated that China has achieved a 14.3% reduction by 2018. In addition to these two overall targets, it is common for specific targets to be set for industrial subsectors. The 2020 goals and 2018 achievements for China's cement and iron and steel subsectors are also provided in Table 2-7.

Table 2-7. Key 2020 Targets for China's Industry Sector

Industry Overall Targets		2020 Goal	2018 Actual
Reduce energy consumption per unit of industrial value-added (compared to 2015)		-18%	-13.6% (2016-2018)
Reduce CO_2 emissions per unit of industrial value-added (compared to 2015)		-22%	-14.3% (est. 2016-2018)
Cement Sector	**Unit**	**2020 Goal**	**2018 Actual**
Improve clinker energy intensity	kgce/t	105	112*
Increase the share of co-processing cement kilns	%	12%	10%
Reduce clinker capacity	Mt	1410	1,716
Increase the utilization rate of clinker capacity	%	≥80%	69%*
Iron and Steel Sector	**Unit**	**2020 Goal**	**2018 Actual**
Improve crude steel energy intensity	kgce/t	560	558
Reduce crude steel capacity	Mt	1,000	1015*, **
Increase the utilization rate of crude steel capacity	%	80%	78%
Increase the ratio of electric arc furnace-produced steel	%	20%	20%

Sources: CCA, 2017a; CCA, 2017b; MIIT, 2016; MIIT, 2017a; Non-Ferrous News, 2018; State Council, 2016a.
*2017 data **Another source estimates this value to be 980 Mt (China Metallurgical Geology Bureau, 2019).

[17]Industrial sector refers to the secondary sector of China's economy, which includes mining, manufacturing, and water production and distribution. Within manufacturing, there are 16 main sub-sectors: food, beverage and tobacco; textiles, chemical fibers, and related products; timber and wood products; paper and paper products; printing and publishing; chemical materials and products; medicines; rubber and plastics; non-metallic mineral products; ferrous metals; non-ferrous metals; metal products; machinery; transport equipment; electric and electronic equipment; and other manufacturing. In this report, industrial sector energy use is also combined with energy use of agriculture and construction sectors, unless noted otherwise.

Table 2-8 provides overview information on the key national energy-related policies and programs for the industry sector that are reviewed here. Half of the 12 industrial sector policies and programs are administrative or regulatory, ranging from mandatory limits to the amount of energy per unit of industrial product produced to mandatory reduction of overcapacity in some industrial sectors to regulatory requirements related to recycling of materials, industrial boilers, and professional energy management training. Four policies rely on economic measures or incentives to control energy use or motivate the increased development of specific high-tech industries. The remaining two policies and programs use information, motivation, and voluntary measures to inspire industries to reduce their energy use and related emissions. Table 2-8 provides an overview of the coverage of these efforts as well as their current status.

Table 2-8. China's Key Energy-Related Policies and Programs: Industry Sector

Policy/Program	Type	Coverage	Current Status
Made in China 2025	Economic	High-tech industries: New Energy Vehicles (including EVs), next-generation information technology and tele-communications, high-end computers, advanced robotics, and AI.	Receiving significant government policy and financial support
Top-Runner Program for High Energy-Consuming Industries	Informational; Voluntary; Motivational	Best performing industries in energy intensive sectors: ethylene, synthetic ammonia, cement, flat glass, electrolytic aluminum, steel, crude oil processing, methanol, and copper smelting	16 and 19 Top Runner enterprises were awarded in 2016 and 2018, respectively, but program design and participation are weak
Unit Energy Consumption Limit Standards	Regulatory/ Administrative	Mandatory energy consumption limit standards in industries such as steel, nonferrous metals, chemicals, building materials, coal, electricity, light industry, petroleum, transportation, etc.	Expanded to cover other areas (e.g., water and recycled resources) with a goal to revise and update 300 key standards by 2020
Differential Electricity Pricing	Regulatory/ Administrative; Economic	Ten energy-intensive industrial sectors, such as cement, steel, and electrolytic aluminum	Continue policy implementation with encouraged expansion of scope and pricing difference when needed at the local level
Boiler Action Plan	Regulatory/ Administrative; Economic	Requirements for reducing energy use and controlling pollution from China's ~300,000 coal-fired industrial boilers	Earlier plan strengthened in 2018 with more stringent standards for coal-fired boilers
Voluntary Commitments Initiative	Informational; Voluntary; Motivational	100 enterprises that have made voluntary energy use reduction or energy intensity improvement pledges	100 enterprises have voluntarily made energy use reduction or energy intensity improvement goals; 15 enterprises were recently commended by NDRC for their good progress
Clean Production Indicator Systems	Informational; Voluntary	Resource extraction, consumption, recycling, and use; re-manufacturing, green	30 clean production evaluation indicator systems for industrial and agricultural subsectors published

		manufacturing, retrofits, energy conservation, water conservation, and emissions reduction	since 2005, with some recently updated and more revisions underway
Green Manufacturing	Economic; Voluntary	Industry wide, focus on energy consumption, water usage, utilization of industrial wastes, recycling, and green energy.	Providing financing support to eligible companies and projects
Circular Economy	Regulatory/ Administrative; Economic; Informational; Voluntary	Focuses on recycling and remanufacturing	Current work focuses on recycling and remanufacturing and also overlaps with clean production and green manufacturing
Mandatory Reduction of Production Overcapacity	Regulatory/ Administrative	Steel, cement, and coal sectors	Steel and coal sectors achieved 13th FYP targets ahead of time while cement sector sees challenges of meeting its target; steel sector faces renewed risk of overcapacity due to increased market price after the capacity cut
Energy Management and Professional Training Program	Regulatory/ Administrative (for large enterprises in Beijing); Economic; Informational; Voluntary	Pilot program in Beijing, Tianjin, Hebei, Shandong, and Shaanxi	On-going pilot programs in five provinces selected by NDRC; some pilots programs are now self-sustaining
Energy Technology Promotion Catalogue	Informational	15 energy efficiency technologies selected and promoted annually	China joined in the international Top-TEN program and domestically began to provide support for adoption of the recommended technologies

Made in China 2025

China's Made in China 2025 program focuses on developing key high-tech industries, such as EVs and next-generation information technology, and is still receiving significant policy and financial support from the Chinese government.

Announced in 2015, *Made in China 2025* is China's plan to transform its manufacturing sector from a sector that produces low quality and low value-added products in an inefficient and resource-intensive manner to a sector that produces high value-added products and leads in innovative and new emerging technologies. The plan identified ten focus areas including artificial intelligence, robotics, and new energy vehicles. The government promotes and supports these areas through its Five Key Projects, including the development of national manufacturing and innovation centers, smart manufacturing, industrial foundational technologies, green manufacturing, and high-end manufacturing innovation (State Council, 2015a).

Made in China 2025 has both energy intensity and CO_2 emissions intensity reduction goals, aligned with the goals established by the State Council (see Table 2-7 above). Energy consumption per unit of industrial value-added will be reduced by 18% and 34% by 2020 and 2025, respectively, compared to the 2015 level (State Council, 2015a). By the end of 2018, energy consumption per unit of industrial value-added had decreased 13.6%. In order to achieve the 2020 target, China's industrial energy intensity needs to continue decrease another 4.4%, which was the average rate of reduction between 2016 and 2018 (China Environment News, 2017; Ji, 2018; and Yicai, 2018a). The *Made in China 2025* goals for CO_2 emissions per unit of industrial value-added are to reduce emissions by 22% and 40% by 2020 and 2025, respectively, compared to 2015 (State Council, 2015a).

The focus areas and industries that are targeted in *Made in China 2025*, such as electric cars, other new energy vehicles, and semiconductors are being significantly supported by the Chinese government, without specifically citing the *Made in China 2025* initiative (MOF, 2019a). There is reporting that China may replace the plan with a new strategy (Wei and Davis, 2018).

Energy Efficiency Top-Runner Program for High Energy-Consuming Industries

Best performing enterprises in a number of industries have been identified by government officials as Top Runners and progress has been made in reducing the specific energy consumption of these enterprises even though the program has a number of design and implementation weaknesses.

In 2015, the Chinese government launched the voluntary Energy Efficiency Top-Runner Program for High Energy-Consuming Industries such as iron and steel, ethylene, ammonia, and cement (MIIT, 2015a). Every year from 2016 to 2019, the program selected and publicly announced the Top Runners for these industries. The Top Runners are selected based on their specific energy consumption, i.e., energy use per unit of product. Table 2-9 provides the specific energy consumption value of selected Top Runner industries in 2017. Over the years, specific energy consumption values of the Top-Runners have shown a downward trend, indicating improvements in energy efficiency (CEC, 2018; CCIAC, 2019).

Program participants, however, have not received any substantial financial incentives, which has affected the enthusiasm of the companies. In addition, most of the evaluations and selections of Top Runners were done by local governments. The involvement of industrial associations is not clear and seems to be limited. This program structure could compromise the quality of the selection due to lack of familiarity and buy-in from industrial associations (Yu, 2019).

Table 2-9. Specific Energy Consumption of Top-Runners in Energy-Intensive Industries (2017)

Sector and Process	Top-Runner Specific Energy Consumption	Unit
Sintering process in iron and steel sector	38.00	kgce/t
Ethylene sector	501.40	kgoe/t
Ammonia (high-quality bituminous coal)	1,079.00	kgce/t
Ammonia (regular bituminous coal)	1,206.00	kgce/t
Ammonia (lignite)	1,225.00	kgce/t
Ammonia (natural gas)	1,020.00	kgce/t
Petroleum refining	6.55	kgoe/t
Methanol (coal)	1,378.00	kgce/t
Methanol (natural gas)	1,133.00	kgce/t
Methanol (coke oven gas)	1,183.00	kgce/t
Cement	95.70	kgce/t clinker
Flat glass	11.56	kgce/weight case
Electrolytic aluminum	12,817.00	kWh/t
Copper smelting	259.51	kgce/t

Source: MIIT, 2018a.

Unit Energy Consumption Limit Standards

Unit Energy Consumption Limit Standards that have been developed to cover major industrial sectors have recently expanded to cover other areas, such as water energy conservation and recycled material utilization.

China began to develop mandatory Unit Energy Consumption Limit Standards in 2005. Since then, the coverage of the standards has expanded from traditional energy-intensive industries such as steel, nonferrous metals, chemicals, building materials, coal, electricity, light industry, petroleum, and transportation to new emerging areas such as water efficiency and recycling. The government began the process of revising many of the existing standards in 2017 with a goal to update 300 standards by 2020, to reflect the current improvement in energy efficiency and technology adoption (MIIT, 2017b).

Measures for enforcing mandatory unit energy consumption limit standards include making public a name list of enterprises that have not met the standards, requiring those enterprises that have failed to meet the obligation to stop operation and make improvements, and placing those enterprises that have no way to meet the obligation on a phase-out list. The implementation of mandatory energy consumption limit standards is also linked to the implementation of differential electricity pricing (see below).

Differential Electricity Pricing

An innovative policy measure targeted at energy-intensive products by linking mandatory electricity prices with energy-efficiency levels which has led to some success but which also has potential for increased use by local governments to achieve their energy and emission reduction goals.

Currently, seven energy-intensive industrial sectors (such as ferroalloy, calcium carbide, and caustic soda) have differential electricity pricing, where industrial facilities in these sectors pay a higher electricity price. Three energy-intensive sectors - cement, steel, and electrolytic aluminum - also have differential electricity pricing, where the plants with higher energy intensity pay higher electricity prices.

The differential electricity pricing policy began in 2004 and has reportedly contributed to industrial energy efficiency improvement in key sectors (e.g., cement). The government believes that there is more potential savings to be gained from this policy by expanding its use to more provinces and by encouraging local governments to customize it to fit their local conditions, e.g., higher prices and covering more sectors (NDRC, 2018b).

This policy, however, has experienced a number of issues during implementation, such as differences in enforcement across provinces that leads to potential unfair treatment across industries, lack of timely updates on the policies to reflect the latest development in efficiency improvement and technologies upgrades, and varying enforcement of the policy by province which leads to missed energy-savings opportunities.

Boiler Action Plan

China's 2014 national Boiler Action Plan was strengthened in 2018 by banning construction of small and medium coal-fired boilers nationwide and establishing more stringent emissions standards for boilers in selected key areas of China.

Boiler systems are one of the major sources of China's greenhouse gas emissions, accounting for 18% of the nation's total coal consumption and 11% of China's energy-related CO_2 emissions (NDRC, 2014b; Tong, 2018). The large number of small industrial boilers coupled with their dispersed locations and distributions is a significant challenge for realization of China's air pollution prevention and control effort, as well as for China's climate goals.

Since 2007, a number of policy documents have been issued to address China's inefficient, small industrial boilers, setting specific targets and requirements for reducing energy use and pollution from coal-fired industrial boilers, and encouraging switching from coal to other energy sources, such as natural gas and electricity. In 2018, the government banned the construction of small and medium coal-fired industrial boilers. New-built boilers in these key areas must meet "super-low" (i.e., super-stringent) air pollution standards while existing boilers in key areas must meet national or more stringent local emission standards, through energy conservation and emission retrofits (SAMR, 2018).

Voluntary Commitments Initiative

NDRC recently highlighted the good progress 15 of the 100 companies participating in the Voluntary Commitments Initiative made toward reaching their respective energy use reduction or energy intensity improvement commitments.

In 2017, NDRC launched the Voluntary Commitments Initiative, based on the model of voluntary agreements used in a number of countries around the world, including China. The initiative aims to get 100 enterprises to voluntarily participate in the program in which enterprises pledge to implement national and local standards, achieve energy-savings targets, and conduct energy retrofits through 2020. Enterprises that achieve their commitments will receive positive public recognition and government endorsement.

On December 29, 2017, NDRC announced the 100 enterprises that have made pledges, including 16 in the steel and non-ferrous metals industries, 16 in coal and electricity, 17 in the petroleum, petrochemical, and chemical industries, 13 in building materials, 22 in manufacturing, 6 in transport, 5 in the public sector, and 5 in e-commerce and retail (NDRC, 2019a). During the 2018 Energy Conservation Week, local provinces and cities organized a Voluntary Commitments signing and recognition event where, for example, 24 companies from Shiyan City of Hubei Province signed the Voluntary Commitments Initiative (NECC, 2018). In April 2019, 15 companies were highlighted to showcase their progress towards their commitments (NECC, 2019).

Clean Production Indicator Systems

Clean Production Indicator Systems are a key component of China's clean production system and are used to rank industrial facilities in terms of their level of clean production, from domestically average to internationally advanced.

China's clean production system consists of: 1) the *Cleaner Production Promotion Law* (2002), 2) *Regulations on Clean Production Evaluation* (2004, revised in 2016), 3) more than 50 voluntary industrial clean production standards, and 4) more than 30 clean production indicator systems. These regulations, standards, and indicator systems focus on reducing wastes and promoting resource utilization through adopting advanced technologies and improved management practices (People's Website, 2002).

Clean production indicator systems have been or are being developed for more than 30 heavy industries, e.g., steel sector, printing, synthetic fibers, coal washing, and fertilizer manufacturing. The indicator system covers five aspects of a "clean production process," including: production process and equipment, resource and energy consumption, comprehensive utilization of resources, pollution controls, and clean production management. Based on the scoring in each aspect, facilities can achieve one of three levels of clean production: Level I - Internationally Advanced in Clean Production, Level II – Domestically Advanced in Clean Production, and Level III – Domestically Average in Clean Production (NDRC, 2018c; NDRC, 2019b; NDRC, 2019c).

Green Manufacturing

Supporting Made in China 2025, the Green Manufacturing initiative aims to transition and upgrade China's traditional industries to be efficient, clean, and low-carbon using voluntary efficiency targets, demonstration projects, and green lending.

Green Manufacturing, promoted by the Ministry of Industry and Information Technology (MIIT), covers the life cycle of industry activities – from green design, to green procurement of raw materials, clean production, green transport, and circular economy. In 2016, MIIT released the *Industry Green Development Plan* (2016-2020), which set voluntary guiding targets for improving the specific energy consumption of key industrial products (steel, cement, aluminum, ethylene, ammonia, and paper), improving industrial solid waste utilization rates, increasing recycling rates of non-ferrous metals, steel scrap, plastics, and tires, and increasing the share of green and low carbon energy sources in industrial energy use (MIIT, 2016). The purpose of the plan is to support State Council's *Made in China 2025* and the 13th Five-Year Plan.

Most recently, MIIT and the China Development Bank jointly released a notice to accelerate industrial energy conservation and green manufacturing by leveraging green lending, i.e., expanding the use of pledged supplementary lending (PSL) to ecological and environmental protection areas (MIIT, 2019a). Eligible projects in the areas of environmental protection technical retrofits and upgrades, industrial waste gas, waste water and solid waste treatment, resource utilization and recycling, and industrial company relocation can receive low-cost capital support from the China Development Bank and its local branches.

Circular Economy

The concepts of clean production and green manufacturing have been further extended to efforts to develop a circular economy that includes all economic sectors and extends to resource extraction and mining, resource consumption, materials recycling and re-utilization, and behavior changes to reduce waste from by-products and reduce demand for new/virgin materials.

Circular Economy, which became a key policy area during the 11th and 12th FYP periods, goes beyond clean production and green manufacturing to include all economic sectors and extends to resource extraction and mining, resource consumption, resource recycling and utilization, and behavior changes. In 2008, China formulated the *Circular Economy Promotion Law*; and in 2013, the State Council published the *Development Strategies and Near-Term Action Plan of Circular Economy*. Currently, the Circular Economy work in China primarily targets: (1) recycling of industrial waste (the so-called urban mine), (2) re-manufacturing: retooling or upgrading old machinery to reclaim their value, (3) clean production retrofits of coking, building materials, non-ferrous metals, chemicals, and textiles industry and implementing ultra-low emissions retrofits in iron and steel industry, (4) energy conservation, water conservation, and emissions reduction, (5) green manufacturing systems to develop green factories, green parks, green products, and green supply-chains.

Mandatory Reduction of Production Overcapacity

The Chinese government's efforts to reduce industrial overcapacity have made successful strides in the steel, coal, and coal-fired power sectors, with less success in the cement sector and now faces a renewed risk of overcapacity.

Under President Xi's "Supply Side Structural Reform," mandatory reduction of overcapacity in heavy industries became a key emphasis in the 13th Five-Year Plan (FYP). Table 2-10 provides the 2020 goals and the realized reduced capacity during the 2016-2018 period. By the end of 2018, China's steel and coal sectors achieved their 13th FYP overcapacity reduction goals two years ahead of time (NDRC, 2019d). A total of 140 Mt of substandard steel production capacity was eliminated, equivalent of the combined output of the U.S and Germany (MIIT, 2018b). The cement sector, however, has experienced difficulty meeting its target, achieving only 25% of its five-year target by 2018. For the coal-powered sector, while China has already achieved its goals of phasing out small coal-fired power plants during the 13th FYP, it is still adding new capacity of coal-fired power plants. In 2018, China added 33 GW of coal-fired plants (from 2017 to 2018), and added another 33 GW as of November 2019 (from 2018 to November 2019).

In 2019, NDRC announced that it will conduct random inspection on local provinces to ensure no illegal production occurs (NDRC, 2019d). Measures such as satellite remote sensing and electricity use monitoring will be used to check unwanted production, according to the Ministry of Industry and Information Technology (Xinhua Net, 2019b).

Table 2-10. Overcapacity Reduction Targets and Results

	2020 Capacity Reduction Target	2016-2018 Reduced Capacity
Steel	100 Mt	150 Mt
Coal	550 Mt	810 Mt
Coal-fired power	20 GW	20 GW
Cement clinker	400 Mt	100 Mt

Source: NDRC, 2019d.

One unintended effect of this policy was that China's crude steel production increased 6.6% from 2017 to 2018 to 928 Mt largely due to the increased market price of steel products driving up the production after the capacity cuts. In 2018, China's steel industry reported a 39.3% year-on-year profits growth to 470 billion yuan (Xinhua Net, 2019b). Reducing overcapacity in industry faces significant challenges, especially regarding appropriately addressing the issue of laying-off hundreds of thousands of workers and supporting the transition of local economies.

Energy Management and Professional Training Program

Two municipal cities and three provinces are piloting energy management and professional training programs to build capacity in these areas for positions in industrial enterprises.

Energy management systems have been established to play a key role in improving energy use in the 13th Five-Year Plan. Two municipal cities and three provinces - Beijing, Tianjin, Hebei Province, Shandong Province, and Shaanxi Province - have been selected by NDRC as pilots for energy management professional training. For example, Shandong Province has created an Energy Manager Professional Program, which has helped created market demand for energy management specialists (Yu, 2019). The program is now self-sustaining with training, exams, and certification. The Beijing Government requires all industrial enterprises that have an annual energy consumption of 5,000 tce or larger to have an energy management professional position (Beijing Government, 2011).

Implementation of the professional training pilots is conducted by the National Energy Conservation Center (NECC), which is overseen by NDRC. NECC has developed training curriculum and test requirements to be used in all pilots. After participating in training for more than 80% of the training hours, candidates can take the energy management exam in the thermal energy, electrical energy, or both categories. In Beijing, candidates who pass the energy management exam in either of the categories for two consecutive years can receive the Energy Management Professional Certificate, which is valid for three years (Beijing Government, 2011).

Energy Efficiency Technology Promotion Catalogue

This program, in which China promotes energy-efficient technologies both domestically and internationally through the publication of catalogues of selected technologies, is evolving to include not only technology identification, but also support for adoption of these energy-efficient technologies through demonstrations and other promotion techniques.

The Energy Efficiency Technology Promotion Catalogue is a key NDRC program. The China Energy Conservation Association (CECA) is responsible for soliciting submission of technologies while experts are invited to review and select technologies. The National Energy Conservation Center (NECC) conducts the final review for NDRC by focusing on technical and market potentials of the technologies. In the 13th Five-Year Plan, the program has started to look beyond just publishing the catalogues by expanding support for adoption of the recommended technologies. To accomplish this, NECC is now responsible for organizing meetings that bring technology providers and users together to better understand market demands. With an enhanced market understanding, every two years NECC assembles technology experts to identify 15 desirable technologies from several hundreds of recommended technologies for the Catalogue. NECC then aggressively promotes these 15 selected technologies through developing application case studies, offering customized services, and organizing demonstration events. In addition, NECC has established a "National Energy Conservation Technologies Promotion and Demonstration Base" in suburban Beijing to host and exhibit all chosen technologies.

China joined the International Partnership for Energy Efficiency Cooperation (IPEEC) in 2008 and is one of the leading members (along with Australia) of the "Top Ten Energy Efficiency Best Practices and Best Available Technologies (TOP TENs)" Task Group, with other participating members from Canada, France, Japan, South Korea, and the U.S. The goal of the task group is to showcase best available energy efficiency technologies (BATs) and best practices (BPs) in use by business in participating countries (IPEEC, 2018). In 2015, the first lists of international TOP TENs from Australia, China, France, Japan, and the U.S. were published and the second lists from China, France, Japan, and the U.S. were published in 2018 (NDRC, 2018d). The latest list of TOP TENs from China includes ten BATs for industry and ten for the buildings sector, as well as ten Best Practice and case studies for the industrial and buildings sectors (NDRC, 2018d).

Climate Leaders Program

The Climate Leaders Program was launched by Energy Foundation China in October 2017. The purpose of the program is to select and award Chinese companies that demonstrate outstanding contributions to mitigate climate change and to promote energy conservation. The Climate Leaders Program aims to provide technical assistance and a network platform to the companies to continue to increase the market influence of these companies and attract more companies to join the program.

During the program's first year, 2017-2018, 24 companies applied to participate in the Climate Leaders Program. The program conducted comprehensive reviews of the company applications and selected four large companies to be Climate Leaders: GREE Electric Appliances Inc., China Mengniu Dairy Company Limited, Goldwind Science and Technology Co., Ltd., and Capital Airport Holding Company.

The program is operated by the China Council for an Energy Efficiency Economy (CCEEE), a NGO funded through the Energy Foundation China. CCEEE collaborates with technical supporting agencies, such as the Suzhou Energy Conservation Technical Center and the Green World Technical Service Center.

During the first year, the Climate Leaders Program received a significant amount of publicity and news exposure. In addition, the program developed case studies as well as videos to publicize the companies' accomplishments in energy conservation and emissions reduction.

As the Program moves into its second year, it will add an award category of "Climate Pioneers" for small and medium companies, simplify the review process by changing the mandatory onsite review process of every company to selected companies, and regroup the evaluation criteria by focusing on innovation/advancement (energy efficiency and carbon emission levels, technologies, patents, and management practices) and influence of the company (best practice dissemination and industry leadership).

Motivating companies to participate is one of the largest challenges of the Climate Leaders Program. Currently, most award programs in China are led by the government, supplemented with fiscal or funding support.

Information provided by Sang Jing, Managing Director, China Council for an Energy Efficiency Economy (CCEEE), May 5, 2019.

Buildings Sector

Buildings in China have consumed approximately 20% share of total primary energy for more than two decades (Tsinghua University, 2018), with energy consumption nearly tripling since 2000. Buildings are also responsible for 25% of the country's greenhouse gas (GHG) emissions (LBNL et al., 2016). While direct coal use in buildings has dropped significantly, electricity use has increased and now represents 27% of final energy use in residential buildings and 35% in commercial buildings. With rising living standards and a goal of peaking carbon dioxide (CO_2) emissions around 2030, it is critical that China improve building energy performance and reduce associated CO_2 emissions.

To control the rapid growth of energy consumption in the building sector, China's Ministry of Housing and Urban Rural Development (MOHURD) developed policies in the 13th FYP that cover comprehensive energy efficiency in urban residential, commercial and public, and rural residential buildings (MOHURD, 2017). Table 2-11 provides key policies developed by MOHURD and their 2018 status.

Table 2-11. Key Targets for China's Buildings, 2015 Actual, 2018 Progress, 2020 Goals

	2015 Actual	2018 Progress	2020 Goal
Reduce heating energy intensity in North China urban residential buildings (%)	--	In progress	-15%
Retrofit existing residential buildings (million m^2)	--	In progress	500
Increase the share of energy efficient urban residential buildings in total urban residential building stock (%)	40	> 50	60
Retrofit existing commercial and public buildings (million m^2)		In progress	100
Reduce energy intensity in urban public and commercial buildings (% below the 2015 level)		difficult	-5%
Retrofit rural residential buildings in economic developed regions (%)	-	difficult	10%
Increase the share of green buildings (% of new urban residential and public buildings with energy efficiency 20% greater than 2015 levels)	20	35	50
Increase green buildings total floor space	470 million m^2		2 billion m^2
Increase the share of green building materials in total building materials (%)	n/a		40
Increase the share of prefabricated new construction in total new construction stock (%)	n/a		15
Increase the share of renewable energy in total energy use in urban buildings (%)	4	In progress	6

Sources: MOHURD, 2017; MOHURD, 2019a

Table 2-12 provides information on the key energy-related policies and programs for the buildings sector that are reviewed here. Of the six policies, four are regulatory/administrative programs, and of those, three also incorporate additional economic, informational, or voluntary components. In fact, all of the policies use multiple components to achieve their objectives, demonstrating both the complexity of working within the buildings sector as well as the willingness of the government to combine approaches to create more robust programs.

Table 2-12. China's Key Energy-Related Policies and Programs: Buildings Sector

Policy/Program	Type	Coverage	Current Status
Energy Efficiency Standards for New Buildings	Regulatory/ Administrative	New commercial and residential buildings	In progress. Two residential building energy efficiency standards upgrades have been completed.
Energy Efficiency Retrofits for Existing Buildings	Regulatory/ Administrative; Economic	Energy efficiency retrofits for 500 million m^2 existing residential buildings floorspace, 100 million m^2 of existing commercial and public buildings floorspace	Retrofitting existing buildings is still on-going but with the phase out of the central government retrofit subsidy, retrofit work may be slowed down.
Green Buildings Standards and Labels	Regulatory/ Administrative; Informational; Voluntary	Goal of total green building floor space of 2 billion m^2 by the end of 2020	China upgraded its green building "3-star" standard in 2019 and launched its first green eco-district 3-star standard.
Renewable Energy in Buildings	Economic; Voluntary; Motivational	Increase penetration of solar water heating systems, distributed solar PV in buildings, geothermal technologies, air source heat pump systems	In progress, with technologies such as solar thermal, PV, ground sourced heat pump adoption in buildings.
Energy Efficiency Top Runner Program – Public Sector	Informational; Voluntary; Motivational	Best performer in saving energy, conserving resources, and adopting renewable energy in the public sector.	184 public institutions are awarded Energy-Efficiency Top Runners in 2018 and on the way to select another 200 public sector Top Runners by 2020.
Building Energy Benchmarking and Disclosure	Regulatory/ Administrative; Informational	Administrative office buildings and large public buildings	Active program in Shanghai that includes a city-level building energy performance monitoring platform and energy benchmarking analysis. Program in Changning District to rank and disclose buildings' energy usage performance.

Energy Efficiency Standards for New Buildings

Recently strengthened mandatory building energy efficiency standards for China's new commercial and residential buildings are complemented by advanced voluntary "stretch codes" for new buildings to achieve nearly zero energy performance.

During the 13th FYP, China has upgraded its commercial and residential building codes and standards to a 65% efficiency level compared to its 1980s baseline. In cold climate zones, the national building energy efficiency standards for residential buildings have reached a level that is 75% higher compared to the 1980s baseline performance level.

The recently-released *Nearly Zero Energy Building Energy Efficiency Standard* provides design requirements and performance targets for buildings to achieve nearly zero energy performance

(MOHURD, 2019b). The development of such advanced standards (also called "stretch codes") provides the technical basis for local demonstration projects.

Energy Efficiency Retrofits for Existing Buildings

Retrofits of existing residential, commercial, and public buildings are progressing in line with the 13th FYP goals, but the phase-out of government subsidies and the building services level improvements are making it challenging to reduce overall building energy intensity levels.

Retrofitting existing building is greatly important to reducing energy use in the Chinese building sector. MOHURD issued aggressive existing building retrofit policies since the 11th FYP. By the end of the 12th FYP, this effort resulted in existing residential building retrofits of 990 million m^2 floor space in North China and 70.9 m^2 million in China's transition climate zone. In the 13th FYP, the goal is to retrofit an additional 500 million m^2 of floor space of existing residential buildings and to finish all existing building retrofit work in North China (MOHURD 2017).

One concern regarding the existing building retrofit policy is that China started to phase out the existing building subsidy in 2015 and is trying to leverage market mechanisms to invest in building energy efficiency. As China's existing building retrofit market, especially for urban residential buildings, is mainly driven by government public fund investment, the transformation of the central government subsidy to incentives from local governments combined with market mechanisms increases the uncertainty of China's existing building retrofit progress. For public and commercial buildings, market mechanisms to leverage green financing investments in retrofitting existing buildings are still lacking. The challenge for public and commercial building retrofits is that building service levels (e.g. heating and cooling demand increase due to comfort level improvement, and increased use of building appliances due to higher living standards) have been continuously improving during the 13th FYP. Thus, even though China has an aggressive public building retrofit program, the overall energy intensity of these buildings may not be reduced by the end of the 13th FYP due to building service level improvement.

Green Buildings Standards and Labels

13th FYP goals and supporting policies for increasing the share of green buildings in new construction to 50% have been successful even though implementation has been mostly in eastern China and the less stringent design labels are used more frequently than operational labels.

China has developed comprehensive supporting policies for its green building rating system, which applied to buildings that employ sustainable features such as energy efficiency, water efficiency, green materials, good indoor environmental quality, sustainable construction site management, etc. By the end of the 12th FYP, China developed 4071 green building projects certified with green building labels (the "three-star" label). Many cities such as Beijing and Shanghai have established policies to mandate that new public and commercial buildings achieve green building requirements. Government invested public buildings (government offices, schools, hospitals, etc.) are also required to be green buildings in these cities. In the

13th FYP, China further developed its green building policies to include a target that at least 50% of total new construction needs to be comprised of green buildings, with a goal of total green building floor space of 2 billion m^2 by the end of 2020. To achieve the target, China recently revised its green building rating standards and updated the comprehensive requirements for energy, water, and materials. China upgraded its green building "3-star" standard in 2019 and launched its first green eco-district 3-star standard. It is estimated that by the end of 2020, China will achieve over 50% green building penetration rate for new construction, which outperforms the 13^{th} FYP target.

Renewable Energy in Buildings

The 13^{th} FYP increased the goal for renewable energy use in China's buildings from 4% in 2015 to 6% 2020.

During the 12^{th} FYP, China established renewable energy demonstrations in 46 cities, 100 counties, and 8 solar energy utilization provinces. In addition, 398 solar PV demonstration buildings projects were built with total solar PV installation capacity of 683 MW. By the end of 2015, over 3 billion m^2 of urban construction floor space was served by solar thermal hot water systems and 500 million m^2 of floor space was served by geothermal technologies. The overall renewable energy replacement of commercial energy use reached 4% by the end of the 12^{th} FYP.

In the 13^{th} FYP, China developed ambitious targets for renewable energy utilization in buildings. The plan sets out targets to further increase the renewable energy utilization rate in total building energy consumption from 4% in 2015 to 6% in 2020. Specific targets are (MOHURD 2017):

- Add another 2 billion m^2 urban construction floorspace with solar water heating systems.
- Develop 10 MW of distributed solar PV applications in buildings.
- Add another 200 million m^2 urban construction floorspace with geothermal technologies.
- Encourage use of air source heat pump systems and establish mechanisms for system evaluation, defrost, low temperature operation, etc.

A set of technical standards for renewable energy technologies design, installation, and operation will be revised during the 13th FYP.

Energy Efficiency Top-Runner Program – Public Sector

With the goal of having at least one Top-Runner per province per public building category, the government has awarded 184 public institutions as public sector Energy Efficiency Top Runners by 2018.

In 2017, the National Government Offices Administration (NGOA) along with NDRC and the Ministry of Finance (MOF) announced that the program would: (1) create 1,500 demonstration public institutions by 2018 (50% of the 13^{th} FYP goal) and (2) select 200 Energy Efficiency Top-Runners (NGOA, 2017a). In order to be awarded with the "Energy Conservation Demonstration

Public Institution" title, public institutions must meet a set of evaluation requirements covering energy conservation targets, energy efficiency, water efficiency, energy management, use of PV or solar thermal systems, and green procurement. Extra credit is given for additional actions such as online energy use monitoring, geothermal utilization, innovation in energy conservation, and utilization of non-traditional water resources (NGOA, 2017b). The Energy Conservation Demonstration Public Institutions have to meet their energy-saving targets for the most recent two years and achieve a total score of 85 points or higher on a 100-point scale.

In May 2018, NGOA announced that a total of 184 public institutions were awarded the public sector Energy Efficiency Top-Runners designation (NGOA, 2018). Among the 184 institutions, 154 installed solar PV or solar thermal, 152 conducted energy audits, 142 were equipped with charging stations for electric vehicles, 127 implemented energy-consumption monitoring systems, 95 explored energy performance contracting, 28 utilized shallow ground geothermal resources, and 24 developed energy management systems (NGOA, 2018). NGOA plans to update the list of Top-Runners every two years (NGOA, 2017a). In 2019, NGOA announced plans to create 1,400 Energy Conservation Demonstration Public Institutions by 2020 and to select 200 Energy Efficiency Top-Runners (NGOA, 2019).

Building Energy Benchmarking and Disclosure[18]

A few cities and local governments in China are implementing building energy benchmarking and disclosure policies to improve building energy performance and reduce associated CO_2 emissions.

One of the measures that cities and local governments in China are undertaking is toimplement building benchmarking and disclosure policies. For example, Shanghai announced an Energy Consumption Monitoring Platform for administrative office buildings and large public buildings in March 2014 (SCTA, 2014) to support Shanghai's overall goal of retrofitting no less than 10 million square meters (m^2) of public buildings from 2015 to 2020 (Shanghai Housing and Urban-Rural Development Management Commission, 2016). Under this mandatory policy, a city-level building energy performance monitoring platform was implemented to collect, analyze, and monitor building energy use in government office and large public buildings. In addition to energy performance monitoring and analysis, the platform provides comprehensive evaluation of energy usage, benchmarking analysis, and target-setting functions.

The Shanghai Academy of Building Research is required to conduct energy benchmarking analysis to compare similar buildings and provide energy-use characteristics and average values for each type of building (NRDC, 2017). The energy performance monitoring platform provides opportunities for benchmarking horizontally (across different buildings in the same type) and vertically (self-comparison over-time). Thus, energy-saving potentials of different types of buildings can be identified, and scientific evidence can be provided for developing energy-saving policies and technologies in the buildings sector.

[18] These are also referred to as benchmarking and transparency policies.

Currently, Shanghai's Changning District, which has operated a comprehensive building energy performance monitoring platform for the district since 2011 (Szum et al., 2019), is undertaking initiatives to improve upon Shanghai's initial benchmarking and transparency practices (NRDC, 2018)

Better Buildings China Program

The Better Buildings China program was established under the U.S.-China Energy Efficiency Action Plan (EEAP) by the U.S. Department of Energy and China's NDRC based on the successful experience of the U.S. Better Buildings program. The China program, implemented by the China Association of Building Energy Efficiency (CABEE), has 15 partners and organizations. Alliances for green hospitals, green universities, and green commercial office buildings have been established. The Better Building China Program also created a commercial building commissioning committee to provide technical assistance to the stakeholders participating in the program. Besides the alliances and technical committees, the program has also worked with a local building retrofit, benchmarking, and data disclosure pilot in the Changing District of Shanghai. The program provides measurement and verification trainings as well as energy data and total building energy calculation trainings.

The U.S. Better Buildings program uses a multi-pronged approach to drive improvements in energy efficiency across the residential, commercial, and industrial sectors. Launched in February 2011, the program targets a 20% improvement in energy efficiency across different types of buildings over a 10-year period. The program has four main pillars: Market Leadership, Better Information, Federal & Community Leadership and Workforce Development. Within the market leadership pillar, there are three key programs: Better Buildings Challenge, Better Buildings Alliance, and Better Buildings Accelerators. Each of these programs complements each other and the Better Buildings program's successes, along with its evolution over time, offer an example of how, with the right tools, the government can partner with businesses to achieve significant strides in energy efficiency

Appliances and Equipment

Table 2-13 provides information on the energy-related policies and programs for appliances and equipment that are reviewed here. Five of the six policies are regulatory/administrative in nature, with some combining important informational elements as part of the mandatory policy in order to provide consumers with important knowledge to guide purchasing decisions. One policy – to increase fuel switching and reduce dispersed coal for specific types of equipment – combines economic incentives with more regulatory phase-out targets. Only one policy is fully voluntary, using information and motivation to highlight the best-performing appliances in terms of their energy efficiency.

Table 2-13. China's Key Energy-Related Policies and Programs: Appliances and Equipment

Policy/Program	Type	Coverage	Current Status
Mandatory Appliance Energy Efficiency Standards	Regulatory/ Administrative	65 residential, commercial and industrial products	73 residential, commercial, and industrial product energy efficiency standards in place, with an innovative proposed revised standard for air conditioners under consideration
Mandatory Energy Labeling	Regulatory/ Administrative; Informational	37 product categories in 5 major fields of household appliances, office and electronic equipment, industrial equipment, lighting equipment and commercial equipment	Recently revised to strengthen the supervision and management of the label and established label requirements for imported products
Top-Runner Program for End-Use Energy Consuming Appliances and Products	Informational; Voluntary; Motivational	Best energy-efficiency performing products in five product categories: clothes washers, lighting products, household refrigerators, flat panel televisions, and variable-speed air conditioners	Expanded product coverage from 3 products in initial pilot program to 5 products
Unifying Standards, Certification, and Labeling for Green Products	Regulatory/ Administrative; Informational	Integrated catalogues of energy saving and environmental labeled products	Sets new direction for aligning various standards, certification, and labeling products; incorporated into new government procurement lists
Green Cooling Action Plan	Regulatory/ Administrative; Informational; Motivational	Major cooling products including household air conditioners and multi-split air conditioning systems	Just released with goals for 2020 and 2030
Increase Fuel Switching/Reduce Dispersed Coal	Regulatory/ Administrative; Economic; Motivational	Building heating equipment, stoves, boilers	New area of policy emphasis for reducing air pollution in Northern China, complemented by city or province-level subsidies

Mandatory Appliance Energy Efficiency Standards

China's most recently proposed mandatory appliance energy efficiency standard for air conditioners is innovative in that it will essentially phase out inefficient fixed-speed room ACs and require adoption of low-GWP refrigerants.

Mandatory appliance energy efficiency standards known as Minimum Energy Performance Standards (MEPS) were first adopted in China in 1989 for eight major products and have since grown to include 73 residential, commercial, and industrial products, with some product standards having undergone several revisions. Most recently, China is revising its fixed-speed and variable-speed room AC MEPS and has proposed combining them into a single standard to help promote more efficient variable-speed room ACs (CNIS, 2019). The proposed AC MEPS also explicitly considers the adoption of low Global Warming Potential (GWP) refrigerants for new ACs.

Over the past thirty years, China has improved and refined its standard-setting process and worked on strengthening national and local enforcement of these standards, but challenges with limited funding and resources, lack of consistent revisions, and monitoring and enforcement remain (Khanna et al., 2013; Zhou et al., 2013).

Mandatory Energy Labeling

China continues to strengthen its mandatory energy consumption label, with the recent addition of the Top-Runner designation to identify the most-efficient products on the market.

In 2005, the mandatory categorical energy information label known as the China Energy Label was established and there have subsequently been published 14 rounds of covered products, including 37 product categories (e.g. residential air conditioners) in household appliances, office and electronic equipment, industrial equipment, lighting equipment, and commercial equipment. The 14th round, including household ventilators and commercial stand-alone refrigerated cabinets, was implemented in June 2018.

The China Energy Label includes a rating for similar models from efficiency grades of 1 to 3 or 1 to 5, depending on the spread of product efficiencies, with grade 1 being the most efficient. This label seeks to pull the market for efficient products by providing information for consumers to identify and compare the energy efficiency of similar product models in their purchase decision-making. In 2016, label supervision and management were strengthened with a revised administrative law, along with an updated design incorporating the new Top Runner logo where applicable, and new QR code for smart phones (NDRC, 2016d, China Appliance Network, 2016).

Top-Runner Program for End-Use Energy Consuming Appliances and Products

The voluntary Energy Efficiency Top-Runner program selects the most energy-efficient appliances and publicizes them in an annual catalogue that is promoted by the Chinese government.

The voluntary Energy Efficiency Top-Runner program was created in December 2014 to recognize qualifying products as super-efficient on the China Energy Label, based on a scored ranking. The pilot phase of the Energy Efficiency Top-Runner program for appliances from 2015 to 2016 included flat panel televisions, household refrigerators, and variable-speed room air conditioners. The nominated products are evaluated, scored and ranked, and the top 10 to 20 products with overall outstanding performance are awarded the Top-Runner designation. In early 2016, the first catalogue of selected Energy Efficiency Top-Runner products was published jointly by NDRC, MIIT and AQSIQ and included 150 models nominated by 18 manufacturers. The program was expanded to include clothes washers and lighting products in late 2017 (NDRC, 2017e; Yu, 2019), and a second catalogue of selected products was published in late 2018.

Unifying Standards, Certification, and Labeling for Green Products

Green products are emerging as a new area for greater policy coordination across existing environmental product standards, certification and labeling programs.

The State Council issued guidance to establish a scientific, integrated, authoritative, and unified green product standards, certification, and labeling system (State Council, 2016b) in November 2016, followed by implementation of standards for green product assessment in May 2017. In February 2019, NDRC also issued a notice to combine the previously separate government procurement lists of products with environmental labels and energy-saving products into integrated catalogues of green products for government priority and mandatory procurement (MOF, 2019b).

Green Cooling Action Plan

China just released the Green Cooling Action Plan to support efforts to meet its commitment to the Montreal Protocol Kigali Amendment HFC phase-down schedule.

On October 15, 2016, China joined more than 140 countries in signing the *Kigali Amendment to the Montreal Protocol* (UN, 2016), which focuses on phasing down climate-warming pollutants known as hydrofluorocarbons (HFCs) with high global warming potential (GWP). Under the amendment, China committed to freeze its HFC production and consumption by 2024, and reduce in subsequent time steps ending in 85% reduction from baseline levels by 2045.

In June 2019, China released the *Green Cooling Action Plan* (NDRC, 2019e) in support of its commitment under the Montreal Protocol Kigali Amendment HFC phase-down schedule. This plan provides a guide for improved space cooling in buildings, cooling for industrial production, cold-chain logistics (temperature-controlled supply chain), and the cooling servicing sector. The new Action Plan set targets for 2020 and 2030 as shown in Table 2-14 (EFC, 2019).

Table 2-14. Green Cooling Action Plan Targets for 2020 and 2030

	2020	2030
Additional improvement in energy efficiency of major cooing products	30% compared to existing MEPS	25% compared to 2022 levels
Increase in cooling energy efficiency of large public buildings		30% from current levels
Increase in market share of green and efficient cooling products	20%	40% compared to 2022 shares
Annual electricity savings	100 billion kWh	400 billion kWh

Increase Fuel Switching/Reduce Dispersed Coal

In North China, fuel switching and technology upgrades are being promoted in national policies and subnational subsidy programs not only to reduce energy use, but also to alleviate air pollution related to dispersed coal use.

In support of national environmental and air quality goals to reduce low-quality, highly polluting, dispersed or scattered coal combustion, a number of regional and city-level policies have been adopted to promote fuel switching in building equipment use. New policies released in Northern China over the last year focused on immediate action to reduce dispersed coal use, including elimination of all small coal-fired boilers that use dispersed coal in rural residential households in the Beijing-Tianjin-Hebei (Jing-Jin-Ji) region by 2020, setting specific targets for alternative heating technologies to replace dispersed coal boilers, and an overall 2020 phase-out target for Jing-Jin-Ji (State Council, 2017; MEE, 2016; MEE, 2018). In addition to targets, a number of municipalities and provinces have launched subsidy programs for electric heating equipment (e.g., Beijing, Hebei, Shanxi, Gansu) and natural gas equipment (e.g., Beijing, Tianjin, Hebei). It was estimated that dispersed coal consumption in provinces under the program had fallen by 61 Mt in 2018 (CEC, 2019c).

Improving Energy Efficiency and Reducing GHG Emissions from Cooling Equipment

HFCs are currently the fastest growing category of GHGs, growing at the rate of 10–15 percent per year. Growing demand for air-conditioning and refrigeration, especially in emerging economies like India, Indonesia, and China, is also contributing to the rising demand for HFCs. Market potential in these countries is very high for a number of reasons, including hot climates, growing incomes and electrification, and growing urbanization—and also because relatively small proportions of the large and growing population currently own air conditioners (ACs). Air conditioner sales in many emerging high population economies such as Brazil, India, and Indonesia are growing at 10–15 percent per year, and current penetration rates are still low. In India, for example, market penetration of room ACs was about 3 percent in 2011. In China, urban household penetration of room ACs has quickly increased from 5 percent in the mid-1990s to 126 percent in 2012, but rural ownership rates were still below 34 percent in 2014.

In part, due to their significant contribution to residential and commercial energy use, ACs are also typically one of the first appliances for which energy efficiency standards, labels, procurement, incentives, and other types of efficiency programs are adopted worldwide. Since both refrigerant transition and efficiency improvement require redesign of the equipment and retooling of manufacturing lines, ensuring such efforts are coordinated has the potential to keep costs low for consumers, manufacturers, and funding agencies.

In October of 2016, nearly 200 Parties agreed to amend the Montreal Protocol in Kigali, Rwanda, to phase-down consumption and production of hydrofluorocarbons (HFCs) by 2050. In its HFC Primer, the Institute for Governance & Sustainable Development (IGSD) discussed how fast action under the Montreal Protocol could limit growth of HFCs, prevent 100 to 200 billion tonnes of carbon dioxide equivalent (CO_2-eq) emissions by 2050, and avoid up to 0.5°C of warming by 2100, with additional climate benefits from parallel improvements in energy efficiency of air conditioners and other appliances.

Excerpt from Shah et al., 2017.

Transport Sector

China's transport sector used 395 Mtce and was responsible for just over 9% of China's total primary energy use in 2018, having increased significantly from 1980 when the sector consumed 29 Mtce, which was only 5% of total primary energy consumption. This period witnessed profound changes in how goods and people move around China. From an early heavy reliance on rail, China moved increasingly into expansion of road transport, constructing an extensive national network of highways and roads and supporting the growth and modernization of the motor vehicle industry. At the same time, air travel became more prevalent as airports were constructed in all major cities. The emergence of high-speed rail networks dramatically reduced the time for people to travel between cities. Due to heavy dependence on petroleum, a rapid growth of the transport sector led China to become a net oil importer in the 1990s and the largest oil importer in the world at present, leading to increasing concerns over energy security.

Table 2-15 provides information on the key energy-related policies and programs for the transport sector reviewed here. Three of the four are regulatory/administrative in nature – with one combining this approach with economic incentives - while the fourth is an economic-based policy that provides subsidies for specific advanced technologies vehicles.

Table 2-15. China's Key Energy-Related Policies and Programs: Transport Sector

Policy/Program	Type	Coverage	Current Status
Fuel Economy Standards	Regulatory/ Administrative	Light-duty passenger vehicles, heavy-duty vehicles, freight vehicles, light-duty commercial vehicles	Active fuel economy standards for light-duty passenger vehicles (with efficiency on-par with most international standards) and recently revised heavy- and light-duty commercial vehicle standards.
New Energy Vehicles	Economic	Subsidies and supporting policies for battery and plug-in electric and fuel cell vehicles for municipal fleets	Promotion of NEVs moved from pilot subsidies to national subsidies. Subsidies for EV cars were cut substantially in March 2019, but kept for fuel cell vehicles and buses.
Dual Credits Program	Regulatory/ Administrative; Economic	Passenger car companies that produce or import vehicles must meet dual targets for corporate average fuel economy and for new energy vehicle production or imports	Producers or importers of conventional passenger vehicles are provided dual credits to reduce fuel consumption while simultaneously increasing NEV production or imports.
Accelerated Retirement and Phasing Out Internal Combustion Engine Vehicles	Regulatory/ Administrative; Motivational	Phase out > 1 million medium and heavy-duty diesel vehicles below the national III emission standards in the Beijing-Tianjin-Hebei area by the end of 2020; requires heavy-duty diesel trucks to meet national V emission standards	Polluting vehicles unable to meet national emission standards are being phased out, and a national phase-out timetable for all ICE vehicles currently being developed.

Fuel Economy Standards

China continues to have an active fuel economy standards program, covering light-duty passenger vehicles as well as heavy-duty and light-duty commercial vehicles.

China's current mandatory fuel economy standard for light-duty passenger vehicles was last revised in 2014 and is in effect through 2020 (MIIT, 2014). The Phase IV standard that became effective in January 2016 set a fleet average target of 5.0 liters per 100 kilometers (L/100 km, about 48 miles per gallon) for new passenger cars sold in 2020, or 27.5% reduction from the 2015 target of 6.9 L/100 km. Figure 2-3 compares China's historical fuel economy performance and current standard requirements with other existing international fuel economy trends and standards, normalized to the U.S. corporate average fuel economy test cycle, and shows that China has moved from lagging to leading in terms of global fuel economy comparisons but still is behind both the EU and South Korea.

During the 13th FYP period, China also revised its fuel consumption limits for heavy-duty commercial vehicles (effective on July 1, 2019) and for light-duty commercial vehicles (effective on January 1, 2018) (MIIT, 2015b; MIIT, 2018c). Although heavy-duty vehicles constitute only 10% of China's new vehicle market, they account for around 50% of road fuel consumption and fuel economy averages 44L/100 km compared to 39L/100km in the US and 36-38L/100km in the EU (ICCT, 2016).

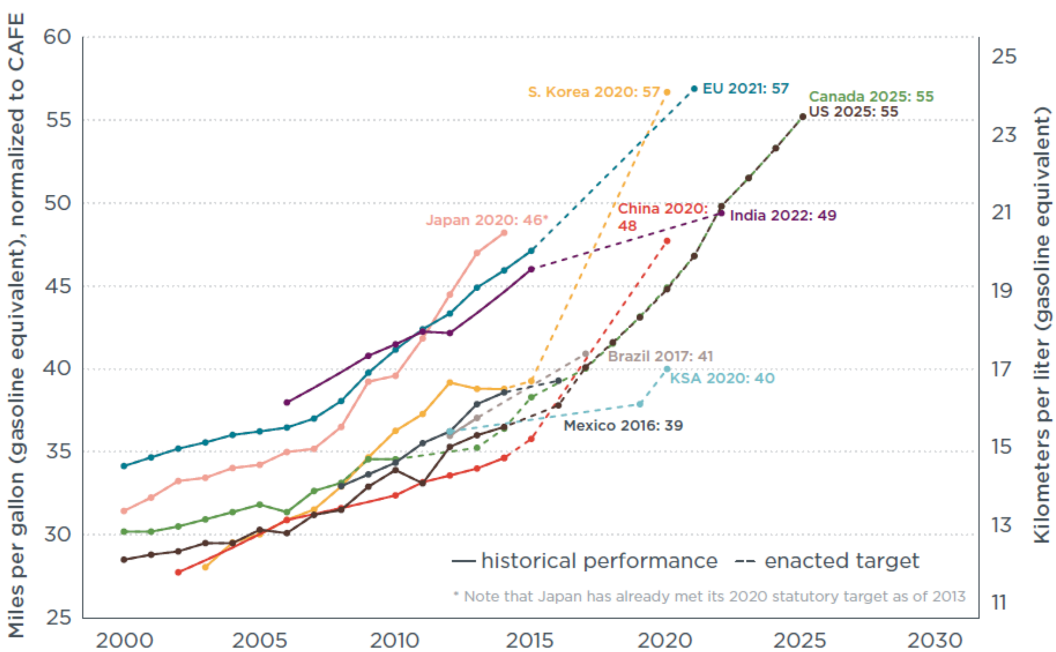


Figure 2-3. International Comparison of Historical Passenger Car Fleet Performance and Current Standards

Source: Yang and Bandivadekar, 2017.

Note: mpg normalized to U.S. CAFE test cycles

Subsidies for New Energy Vehicles

China has seen a rapid growth in sales of New Energy Vehicles (NEVs) as a result of its aggressive pilot subsidy programs, some of which have recently been substantially reduced with potential full phase-out after 2020.

China's Ministry of Science and Technology (MOST) and the Ministry of Finance (MOF) started the *Ten Cities, Thousand Vehicles* program in January 2009 to provide national and local subsidies for qualifying pilot cities to purchase New Energy Vehicles (NEVs), which include battery and plug-in electric and fuel cell vehicles for their municipal fleets. The pilot subsidy program was renewed, refined, and expanded in 2013 to include 39 pilot cities with additional deployment, procurement and local incentive requirements for pilots (Gong et al., 2013; MIIT, 2013). The subsidy amounts were increased in 2014 and 2015 due to slow NEV sales, but gradually reduced since 2016 in response to rapid growth in NEV sales (MOF, 2016), as shown in Table 2-16.

Table 2-16. New Energy Vehicle Sales and Central Government Subsidies

	Sales ('000)	Central Gov't Subsidy (billion RMB)
2012	11	36.4
2013	17	
2014	84	
2015	379	
2016	500	50.3
2017	770	9.084*
2018	1,256	100**
2019		
2020		

Notes: *Partial, **Estimated
Sources: CCID, 2019; Qiu, 2019.

NEV development in China has also been supported by the adoption of a series of complementary policies from late 2016 through 2019 as shown in Figure 2-4. In 2017, the government raised the technical thresholds (e.g. driving range) for NEVs and NEV manufacturers, set caps on central and local NEV subsidies, and improved the payment method for subsidy funds (MIIT, 2017c; MOF, 2016). In 2018, policies were also introduced to exempt NEVs from vehicle purchase taxes, to establish a complete battery recycling system, and to support the planning and development of NEV charging infrastructure facilities.

Total Central Government spending on subsidies are estimated to have reached nearly 100 billion RMB (about $US14.7 billion), with a further 100 billion RMB expected for 2018, 2019 and 2020, not including unknown expenditures from local matching programs. In 2019, subsidies were cut substantially by 47-60% depending on driving range for NEV cars sold in 2019; buses and fuel-cell vehicles were exempted from the cuts (Ren, 2019). In 2019 it was announced that local subsidies will be phased out after the transition period beginning on March 26, 2019 (MOF, 2019c).

In 2018, the total NEV stock in China totaled 2.3 million and accounted for half of the global electric car stock (IEA, 2019d). In 2019, NEVs sales are projected to reach 1.8 million (CCID, 2019).

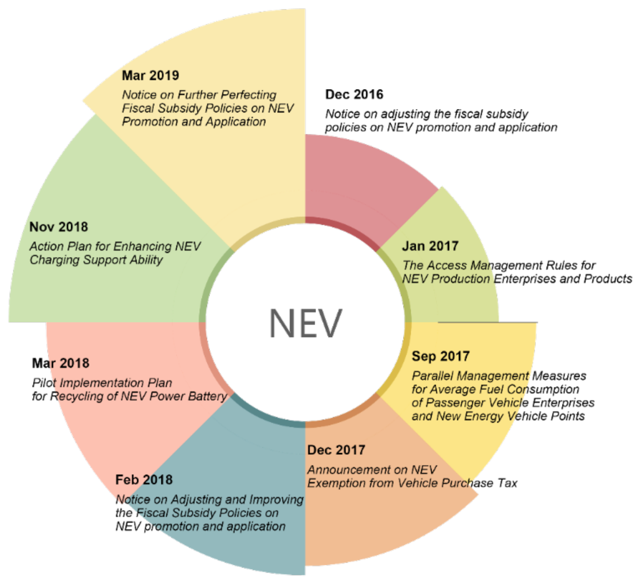


Figure 2-4. National New Energy Vehicle Related Policies from Late 2016 to Early 2019
Source: compiled by authors

Dual Credits Program

Passenger car companies that produce or import passenger vehicles must meet dual targets for corporate average fuel economy and for NEV production or imports.

The "Dual Credits" system for reducing fuel consumption of conventional vehicles while simultaneously increasing NEV sales was formally adopted in September 2017 and implemented in 2018 to reduce transport fossil fuel consumption while increasing NEVs (MIIT, 2017d). The program requires passenger car companies that produce or import more than 30,000 vehicles to meet dual targets for corporate average fuel economy and for NEV production or imports. Surplus NEV credits can be sold, while surplus corporate average fuel economy credits can be banked for future use or transferred to affiliated companies. In July 2019, MIIT proposed amendments to the program that would increase the required ratio of NEVs to 14%, 16%, and 18% for the years of 2021, 202,2 and 2023, respectively, up from 10% in 2019 and 12% in 2020 (MIIT, 2019b).

Accelerated Retirement and Phasing Out Internal Combustion Engine Vehicles

New policy efforts are addressing pollution impacts of older internal combustion engine vehicles, with a national phase-out timetable under development.

In parallel with policies to promote NEVs, China has also proposed phasing out more than 1 million medium and heavy-duty diesel vehicles below the national III emission standards in Jing-Jin-Ji by end of 2020, and to require heavy-duty diesel trucks meet national V emission standards (State Council, 2018; MEE, 2019c). At the subnational level, cities and provinces including Hangzhou, Nanjing, Beijing, Shenzhen, Jinan, Hainan, and Shaanxi have also set local targets for phasing-out polluting gasoline and diesel vehicles below the national III emission standards for 2018 through 2020, with varying levels of subsidies offered per vehicle. In addition, the Ministry of Industry and Information Technology (MIIT) has initiated research into setting a national timetable for the phase-out of conventional internal combustion engine vehicles, but a specific timeline has not been set.

Case Study: Full Electrification of Shenzhen City Municipal Fleet and NEV Promotion

As one of the earliest NEV pilot cities, Shenzhen has been actively promoting the adoption of NEVs in its municipal fleet and for private purchase through local programs and policies since 2009. In 2015, Shenzhen set a goal of achieving 100% pure electric buses in the city within three years. By the end of July 2015, Shenzhen added 11,041 NEVs including 1,771 hybrid electric buses, 1,253 electric buses, 26 electric mini-buses, 175 electric fleet cars, 520 NEV government vehicles, 62 fuel cell vehicles, 850 electric taxis, and 6,374 NEV private cars (C40 Cities, 2018). For the electric bus fleet, a 90% electrification rate was reached in 2016 with 14,695 electric buses and the 100% electrification goal was met in September 2017 (Shenzhen Transportation Bureau, 2017). In addition, the city's taxi fleet also reached virtual 100% electrification in January 2019 with over 20,000 electric taxis in the fleet (Sohu News, 2019).

For 2016 through 2020, Shenzhen plans to construct 8246 quick charging piles for electric buses, 10,800 public quick charging piles and 115,000 slow charging piles to meet its goal of 120,000 NEVs by 2020 (C40 Cities, 2018). In addition, minimum charging pile requirements will also be set for new residential, public buildings and public parking garages as well as commercial and industrial projects.

To support this rapid adoption of NEVs within its city boundaries, the Shenzhen municipal government set up a 5 billion RMB (US$728 million)[19] fund to subsidize NEV purchases, construct charging infrastructure and establish systems for technical standards and research to support NEV technical development (C40 Cities, 2018). Subsidies were offered for electric buses and matching subsidies were offered for private purchases of NEVs. Investors for charging infrastructure development can also receive a 30% investment subsidy. Preferential measures were also introduced for electric taxis and logistics vehicles including fuel surcharge exemptions for taxis from June 2018 onwards and preferential use of 24-hour passing lanes for logistics distribution.

[19] Converted using https://www1.oanda.com/currency/converter/ on July 1, 2019.

Power Sector

Between 1980 and 2018, China's electricity production increased dramatically, growing from 300 TWh to 6994 TWh. Power generation has always been and is still dominated by fossil fuels, which produced 69% of China's electricity in 2019, followed by hydropower (17.8%), wind (5.5%), nuclear (4.8%), and solar (3.1%), with the remaining power produced by other renewables such as biomass and geothermal (0.003%) (CEC, 2019b; CEC; 2020).

Table 2-17 provides information on the key energy-related policies and programs for the power sector that are discussed here. Three of the five policies are regulatory/administrative, setting targets and requiring specific actions regarding the types of power plants that can be constructed as well as establishing rules to reduce curtailment of renewable power sources. The other two policies rely predominately on economic measures to improve the efficiency of China's power grid, especially to allow the various power sources to compete on an economic basis.

Table 2-17. China's Key Energy-Related Policies and Programs: Power Sector

Policy/Program	Type	Coverage	Current Status
Power Sector Reform	Economic; Informational	Developing competitive wholesale and retail electricity markets nation-wide	30% of electricity is competitively procured; 8 spot market pilots launched
Reducing Renewable Electricity Curtailment	Regulatory/ Administrative	National targets and specific targets for key provinces to reduce renewable energy curtailment	Curtailment rates for wind and solar reduced from double-digit to 7% and 3%, respectively
Renewable Energy Obligation Scheme	Regulatory/ Administrative	Establish annual obligations for each jurisdiction in China to achieve minimum consumption levels of electricity produced from renewable energy; launching Renewable Portfolio Standards (RPS)	A renewable energy power consumption annual obligation created
Removal of PV Subsidies and Stimulation of Grid Price Parity of Renewables	Economic; Motivational	Removal of subsidies applicable to China's PV production industry and enterprises	Unexpected removal of PV subsidies in May 2018 that China's PV industry has had to adapt to, stimulating efforts towards reaching the grid parity goal earlier than expected
Addressing Coal-Fired Power Plants	Regulatory/ Administrative; Informational	Limit new coal-fired power plants, eliminate coal-fired power plants using outdated technology, and improve coal power planning and construction	Created a set of policies and established an early warning system to address coal-power overcapacity

Power Sector Reform

Efforts to develop competitive wholesale and retail electricity markets are proceeding, reaching a share of 30% of market-traded electricity at the end of 2018, with 8 provincial spot market pilots launched in 2019.

China launched a new round of power sector reform in 2015 with the issuance of *Opinions on Further Deepening the Reform of Electric Power System* (a.k.a. Document No. 9) and supporting documents (NDRC, 2015b; State Council, 2015b), which provides guidance for making the transition from a government-controlled to a market-based power system that injects diversification of supply and market participants, resource efficiency, and competition into a sector that has long been dominated by the only two state utilities – the State Grid and the Southern Grid – with administratively determined electricity prices.

Guided by Document No. 9, China's national government and provinces are developing competitive wholesale and retail electricity markets. On the wholesale side, the goal is to establish: 1) provincial power markets for formulating weekly, monthly, and annual power contracts between generators and large end-users with prices competitively determined; 2) provincial spot power markets that facilitate intra-day and day-ahead transactions to set prices in real time (Reuters, 2018); 3) regional power markets that enable cross-province, cross-region power trading and multi-province dispatch to enable more resource sharing over a much larger geographic area to reduce costs, renewable curtailment, and emissions. On the retail side, the goal is to open up the retailing business to non-grid companies and foster retail competition that offers end-use consumers the opportunity to select their electricity providers and procure power based on the price of power supplied to them. Over the last 2-3 years, the number of electricity retailers registered in China's power exchanges has reached 3500, a 10-fold increase from 2016 (Yicai, 2018b). By the end of 2018, the share of market-traded electricity in China's total electricity consumption reached 30.2% (China Energy News, 2019).

Guangdong Province has taken a leading role in carrying out power market reform, becoming the first province among the 8 pilots to release its draft spot market implementation plan in August 2018 (Guangdong Province, 2018). According to the plan, Guangdong will build fully-functional power markets step by step that in the near term consist of market settlement of medium- and long-term contracts equipped with a mechanism of adjustment to cover the difference between the fixed price and the market price, a spot market with both day-ahead and intra-day transactions, an ancillary service market initially as a separated market but later integrated, and an integrated regional power market that trades and dispatches power cross the entire Southern region. In the longer term, Guangdong will explore establishment of a capacity market and trading of financial transmission rights among others.

Reducing Renewable Electricity Curtailment

In 2018, China reduced its average curtailment rates for wind and solar to 7% and 3% (from 12% and 6% in 2017), respectively, while generation from wind and solar energy grew by 20% and 50%, respectively, over 2017.

In recent years, fast-paced renewable energy development has created double-digit rates of renewable curtailment in China (Deign, 2017; NEA, 2017a). Renewable-rich regions in western China located far from load centers along the coast combined with other factors such as generators confined by annual generation hour quotas and transmission bottlenecks have contributed to this problem.

China has taken several measures to ease these curtailments. In October 2018, NDRC and NEA jointly issued the *Clean Energy Consumption Action Plan* (2018–2020) (NDRC, 2018e) that sets mandatory national overall targets and specific targets for key provinces in reducing renewable energy curtailment for the next three years. For example, the national goal is to keep the wind energy abandonment rate below 12%, 10%, and 5%, respectively, in 2018, 2019, and 2020 and keep the photovoltaic power abandonment rate below 5% in all three years between 2018-2020. The measures that have been introduced to reduce renewable energy curtailment include barring further projects in provinces where the curtailment rate is high, increasing transmission capacity between the renewable-rich provinces and load centers in the east and south, and encouraging renewable energy to participate in the country's power markets.

In 2018, China reduced its average curtailment rates for wind and solar to 7% and 3%, respectively, while generation from wind and solar energy grew by 20% and 50%, respectively, during 2017 (NEA, 2019a). As shown in Table 2-18, renewable curtailment has continued to drop in 2019.

Table 2-18. National Average Curtailment Rates and Total Curtailment for Wind and Solar Power Generation in China, 2017-2019.

	2017	2018	First ½ 2019
Wind			
National average curtailment rate	12%	7%	4.7%
National total curtailment amount (TWh)	41.9	27.7	10.5
Solar			
National average curtailment rate	5.8%	3.0%	2.4%
National total curtailment amount (TWh)	7.3	5.5	2.6

Sources: NEA, 2018b; NEA, 2018c; NEA, 2018d; NEA, 2018e; NEA, 2019b; NEA, 2019c; NEA, 2019d

Renewable Energy Obligation Scheme

A renewable energy power consumption annual obligation has been established to achieve minimum consumption levels of electricity produced from renewable energy for each jurisdiction in China.

NDRC and NEA released the *Notice on Establishing and Improving the Safeguard Mechanism for Renewable Energy Power Consumption* on May 10, 2019, establishing the Renewable Energy Obligation Scheme – similar to the Renewable Portfolio Standard (RPS) in the U.S. - that provides for a renewable energy power consumption annual mandatory obligation for each jurisdiction in China to achieve minimum consumption levels of electricity produced from renewable energy sources (NDRC, 2019f).

China's Renewable Energy Obligation Scheme, which is valid for 5 years and starts formal operation January 1, 2020, consists of two mandatory renewable energy obligation quotas: total renewable power quotas (referred to as "total quotas") and non-hydro renewable power quotas (referred to as "non-hydropower quotas"). Annual renewable energy power consumption responsibility quotas of two types - a binding minimum quota and a motivational quota that exceeds the binding target - will be issued to each province. To encourage provinces to consume more renewable energy, the amount of renewable energy consumed above the motivational quota is excluded from the energy consumption cap set by China's Double Control policy. The obligated party includes retailers that sell power to customers, and power distribution companies that deliver power to end-users, customers who procure electricity in the wholesale market, and companies that consume power produced from their own power plants. While obligated entities are required to complete their quotas primarily from directly consuming renewable energy, China's Renewable Energy Obligation Scheme provides these entities alternatives to compliance, allowing them to procure, at mutually agreed-upon prices, the excess renewable energy consumed by another entity above its annual quotas, and to voluntarily purchase renewable energy certificates (referred to as "green certificates"), similar to the Renewable Energy Credits, or RECs, in the voluntary REC markets in the U.S., that represent the environmental attributes of the power produced from renewable energy projects and are sold separately from commodity electricity.

Removal of PV Subsidies and Stimulation of Grid Price Parity of Renewables

A policy directive was issued to halt subsidizing PV installation, prompting China's PV industry to react with efforts that have led to an earlier-than-expected transition to grid parity.

Having provided China's PV industry with significant fiscal support through direct subsidies, the Chinese government issued a directive on May 31st, 2018, which put an abrupt halt on subsidizing PV installation (NDRC, 2018f). The policy change was due largely to the fact that unprecedented growth in the PV industry resulting from generous subsidies created an unsustainable level of demand for public funding, and to the need for reducing renewable power curtailment. The new policy, however, caught the PV industry by surprise and as a result there were production cuts, price cuts, wage arrears, layoffs, and even bankruptcy (China Business Net, 2018). In the first half of 2019, domestic PV installations were only 11.4GW, a drop of more than 50% from the same period in 2018. Among them, centralized power plants installed 6.8GW, down 43.3% year-on-year, and installed distributed PV capacity was only 4.6GW, down 61.7% year-on-year (SolarBe, 2019).

The new policy has brought profound changes to China's solar industry, driving companies that can only survive through subsidies out of business and pushing the industry to focus on technology development to further reduce PV component costs and improve PV system operation efficiency, work with local governments to reduce non-technical "soft" costs, develop high-value PV+ services such as internet-based applications and PV+energy storage, and increase PV market size through expanding PV business in broader markets including the overseas market. These efforts have led to progress towards grid parity that enables solar power to compete with coal power without a subsidy. Currently, there are eleven provincial jurisdictions where PV generated power reached grid parity in 2019, and three more provinces are expected to reach grid parity by the end of 2020, ahead of the official target of 2023 (Johnson, 2019).

Addressing Coal-Fired Power Plants

China issued a set of policies and created an early warning system for identifying potential risks associated with coal power planning and construction in response to significant coal power overcapacity and worsening emissions.

China is facing significant coal-power overcapacity and consequential worsening emissions. Since 2016, China has issued a set of policies to limit the construction of new coal-fired power plants in response to the problem (NDRC, 2016e; NEA, 2016a; NEA, 2016b). These policy directives plan a series of actions to control coal-fired power expansion. Measures include establishing an early warning system for controlling overcapacity risks associated with coal power planning and construction, enhancing compliance with the government energy cap, tightening control of coal power expansion by ordering construction projects to be slowed down, postponed, or canceled, and eliminating coal-fired power capacity that uses outdated technology. (NEA, 2017).

Besides slowing down unchecked expansion of coal-fired power generation, NDRC and NEA have also attempted to reduce administratively allocated operating hours for existing coal power plants year by year. As such, all coal-fired generation units approved after the issuance of Policy Document #9 will no longer receive the pre-determined allocation of operation hours and are required to fully participate in the power markets and are compensated at market prices (NDRC, 2017c).

To reduce the coal intensity of power generation, the Chinese government has established specific fuel intensity targets for coal-fired generation units. The 13th Five-Year Energy Development Plan urges the power generation sector to keep its overall energy intensity (coal consumption of generating per unit of electricity) below 310 gce/kWh and keep the intensity levels of both existing coal-fired power plants over 600MW and any new plants below 300 gce/kWh by 2020. In 2015, at the start of the 13th FYP, the average energy intensity of existing coal-fired plants over 600 MW was 315 gce/kWh. In 2018, this value has dropped to 308 gce/kWh (Chinapower, 2019; CEC, 2017).

Chapter 3: China's Future Energy Use Outlook

Introduction

This chapter presents the results of a China Energy Outlook 2050 Continuous Improvement Scenario for China's future energy and energy-related emissions using the Berkeley Lab's China Energy Group China 2050 *Demand Resources Energy Analysis Model* (China 2050 DREAM).[20] This Continuous Improvement Scenario assumes that China will fully adopt the maximum feasible shares of today's commercially available, cost-effective energy efficiency and renewable energy supply by 2050. The underlying assumption of the technologies and measures adopted in this scenario is that China will develop and effectively implement all necessary supporting policies and measures, and overcome any existing barriers or challenges to full adoption by 2050. The China Energy Outlook's 2050 Continuous Improvement Scenario results are also compared with similarly defined scenarios in eight other recent outlooks for China, including four by Chinese domestic institutions and four by international institutions. The China 2050 DREAM model results show much lower energy and CO_2 emissions than scenarios developed by other major Chinese and international organizations.[21] This is reminiscent of the Berkeley Lab scenarios from a study in 2010-11 that showed peaking of energy-related CO_2 emissions by 2030 and possibly as early as 2025 depending on policies considered, which was much earlier than the prevailing scenarios at that time. In 2014, just four years later, China committed to peak its energy-related CO_2 emissions by 2030 as part of its intended nationally determined contributions under the Paris Agreement.

China 2050 DREAM is comprised of a demand module consisting of five demand subsectors (residential buildings, commercial buildings, industry, transport, and agriculture) and a transformation module consisting of energy production, transmission, and distribution subsectors. Using the Long-range Energy Alternatives Planning (LEAP) platform (Heaps, 2019), the China 2050 DREAM captures diffusion of end-use technologies and macroeconomic and sector-specific drivers of energy demand as well as the energy required to extract fossil fuels and produce energy and a power sector with distinct generation dispatch algorithms.

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[20] The China Energy Group has developed and used the China 2050 DREAM model to characterize past and future Chinese energy consumption, evaluate the energy and emissions impact of specific policies in the buildings, industrial, transportation, and power sectors, analyze the environmental impacts of CO_2 and SO_2 co-controls, and perform policy and technical efficiency scenario analysis. We have also previously created medium- and long-term energy and emissions scenarios to 2030 and 2050 for China, and evaluated the potential gaps between domestic energy supply and demand. The model has also been used to assess conventional, non-fossil, and non-conventional supply options for China and their potential contributions to future low-emissions pathways. Most recently, the China Energy Group has further refined and aligned modeling methodologies and assumptions of the DREAM Model in joint collaboration with China's Energy Research Institute and Rocky Mountain Institute on the Reinventing Fire: China project to evaluate the maximum energy efficiency and CO_2 emissions reductions available both in terms of technology and policy in China in 2050. For more information, see https://china.lbl.gov/dream

[21] The China National Renewable Organization has a slightly lower CO_2 emissions in 2050.

China 2050 DREAM is based on the use of key macroeconomic and end-use drivers and addresses end-use energy demand characteristics including sectoral patterns of energy consumption, changes in subsectoral industrial output, trends in saturation and usage of energy-using equipment, technological change including efficiency improvements, and links between economic growth and energy demand. The DREAM model has a higher degree of disaggregation of parameters affecting energy demand than the other major scenario models, particularly global models.

The China Energy Outlook's 2050 Continuous Improvement Scenario presented in this chapter assumes full adoption of the maximum shares of commercially available, cost-effective energy efficiency and renewable energy supply by 2050.

Macroeconomic Drivers

China's population is projected to grow until 2030 to about 1.44 billion (Table 3-1), and afterwards to slowly decline to 1.37 billion by 2050. Over the same period, China's urbanization rate is projected to rise from 50% in 2010 to 78% in 2050.

The Chinese economy is projected to continue to grow, however, at a slower rate, with the average growth of GDP declining from 7.6% annually from 2010-2020 to 2.9% annually from 2040-2050.

Table 3-1. Macroeconomic Drivers and Assumptions for China Energy Outlook's 2050 Continuous Improvement Scenario

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

Sources: Energy Research Institute China General Equilibrium Economic Model, Reinventing Fire: China team analysis

Appendix 2 provides detailed sectoral assumptions on activity growth, energy intensity improvement, and fuel switching trends included in this scenario.

China Energy Outlook's 2050 Continuous Improvement Scenario Results

In the China Energy Outlook's 2050 Continuous Improvement Scenario, primary energy consumption peaks in 2029 at 5,400 million metric tons coal equivalent (Mtce). In 2050, China's primary energy consumption is 3,960 Mtce, which is about 10% below the country's primary energy consumption in 2015 (see Figure 3-1). The non-fossil share of primary energy continues to grow, from 5% in 2015 to 29% in 2050, using the direct equivalent method consistent with the IPCC for converting primary electricity.[22] The share of coal in total primary energy decreases from 65% in 2015 to 28% in 2050, while the natural gas share grows from 6% in 2015 to 16% in 2050 and the oil share remains relatively stable at around 21% from 2015 through 2050.

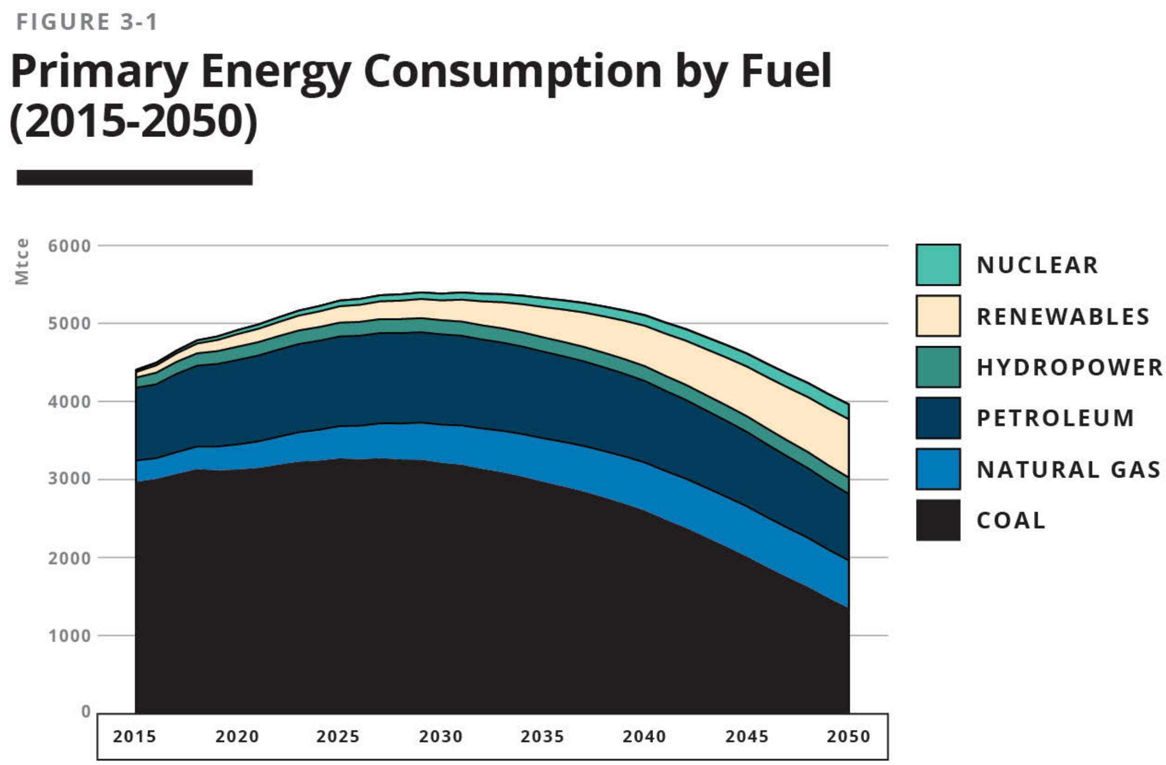

Figure 3-1. China's Total Primary Energy Consumption by Fuel, China Energy Outlook's 2050 Continuous Improvement Scenario (2015-2050)

Figure 3-2 shows the sectoral break-down of primary energy consumption from 2015 to 2050 in the China Energy Outlook's 2050 Continuous Improvement Scenario. With structural shift from heavy industry to less energy-intensive industry, as well as energy efficiency improvement and fuel switching, primary energy consumption for the industry sector peaks by 2025 at 2,790 Mtce. Although remaining the largest sector of energy consumption by 2050, the industry sector share of total primary energy decreases from 59% in 2015 to 43% in 2050.

With continued growth in urbanization and increasing demand for better living quality, the buildings sector primary energy share grows from 22% in 2015 to 27% in 2030. However, with energy efficiency improvement and fuel switching, building primary energy use peaks in 2034 at 1,450 Mtce, and its share of total primary energy is slightly higher (at 30%) than the 2030 level in 2050.

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[22] China 2050 DREAM uses the direct equivalent method (consistent with the IPCC) as the default for converting primary electricity, rather than the Power Plant Coal Consumption (PPCC) method used in Chinese statistics. As a result, the primary energy use presented here are lower than the Chinese equivalent calculated using PPCC. For more details on differences between the two methods, see Lewis et al. 2015.

FIGURE 3-2

Primary Energy Consumption by Sector (2015-2050)

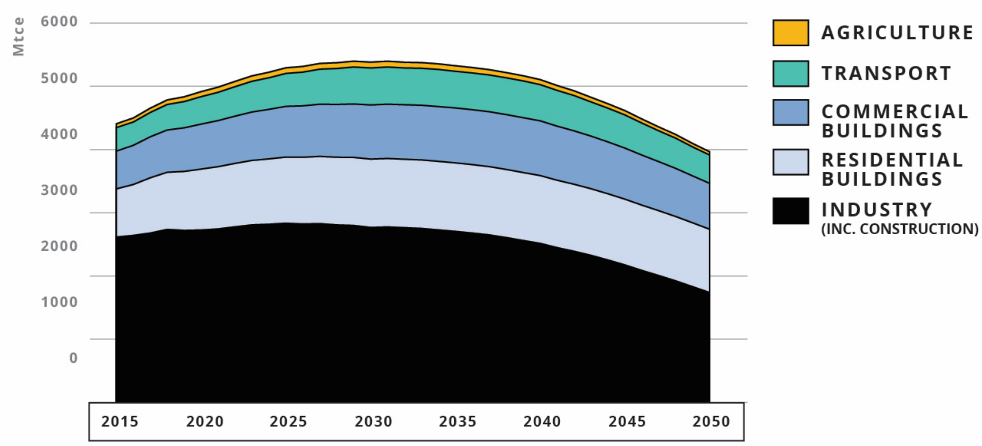

Figure 3-2. China's Total Primary Energy Consumption by Sector, China Energy Outlook's 2050 Continuous Improvement Scenario (2015-2050)

Transportation contributes to a growing percentage of total primary energy consumption, from 17% in 2015 to 25% in 2050, due to rapid growth in private vehicle stock and increasing demand for passenger and freight transport. From 2015 to 2030, total primary energy consumption for transportation grows at an annual average rate of 2.4% before plateauing in the early 2030s as a result of fuel economy improvement and fuel switching. Primary energy use in the transportation sector peaks in 2035 with 1,080 Mtce, and declines slowly at an average rate of 0.5% thereafter.

Electrification—particularly when the electric option substitutes for direct combustion of fuel at greater efficiency at delivering energy services—is a key process to deliver energy savings and emissions reductions as the electricity supply becomes increasingly decarbonized (more evident from consideration of primary energy shown above). With accelerated electrification in the industry, buildings, and transportation sectors, the electricity share of final energy increases from 22% in 2015 to 40% in 2050 (Figure 3-3).

FIGURE 3-3

Final Energy Consumption by Fuel (2015-2050)

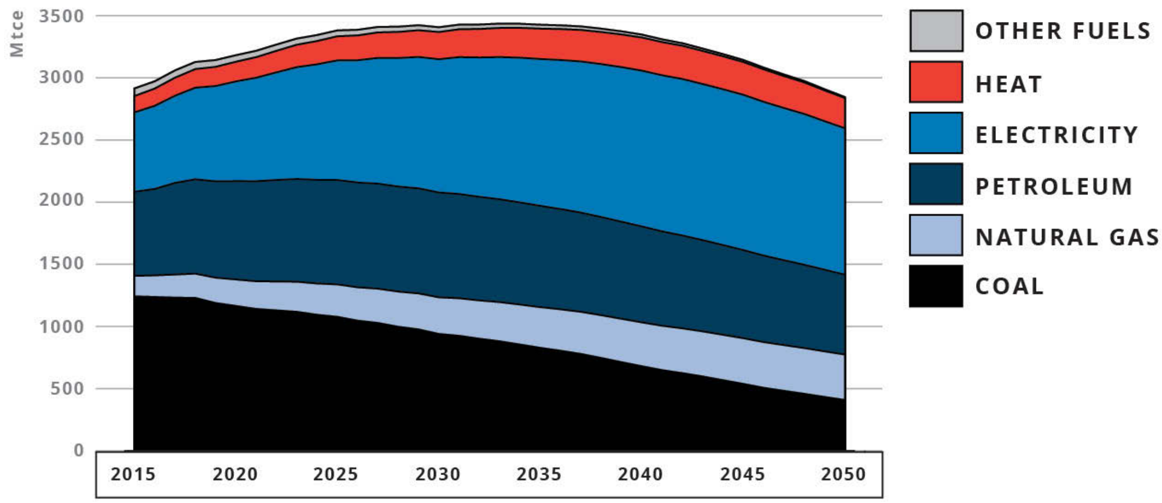

Figure 3-3. China's Final Energy Consumption[23] by Fuel, China Energy Outlook's 2050 Continuous Improvement Scenario (2015-2050)

In the China Energy Outlook's 2050 Continuous Improvement Scenario, China's power system more than triples in size, reaching over 4200 gigawatts (GW) of installed capacity in 2050. Decarbonizing the energy transformation sector (along with energy efficiency) is key to reducing energy-related CO_2 emissions, especially with the electrification in the energy end use sectors. As shown in Figure 3-4, China's power system structure fundamentally changes in this scenario of continuous technological improvement as coal capacity is nearly replaced by cleaner natural gas and non-fossil generation by 2050. This assumes limited new coal power plant expansion in the near-term to avoid stranded coal assets and decreasing costs of wind and solar power that make more renewable power capacity and generation possible. This is particularly true around 2035, when the cost of renewables is expected to drop below the cost of existing coal-fired generation. By 2050, coal capacity is projected to decline to 87 GW, accounting for only 2% of total installed capacity. In contrast, wind and solar installed capacity reaches 2600 GW, which is over 15 times the total wind and solar capacity in 2015 and almost twice the capacity of China's current entire power system (Figure 3-4).

[23] Final energy consumption presented here is the total energy consumed by end-users. Primary energy consumption presented earlier includes energy consumption of the energy sector itself and transformation and distribution losses, allocated back to the demand sectors.

FIGURE 3-4

Power Capacity by Technology (2015-2050)

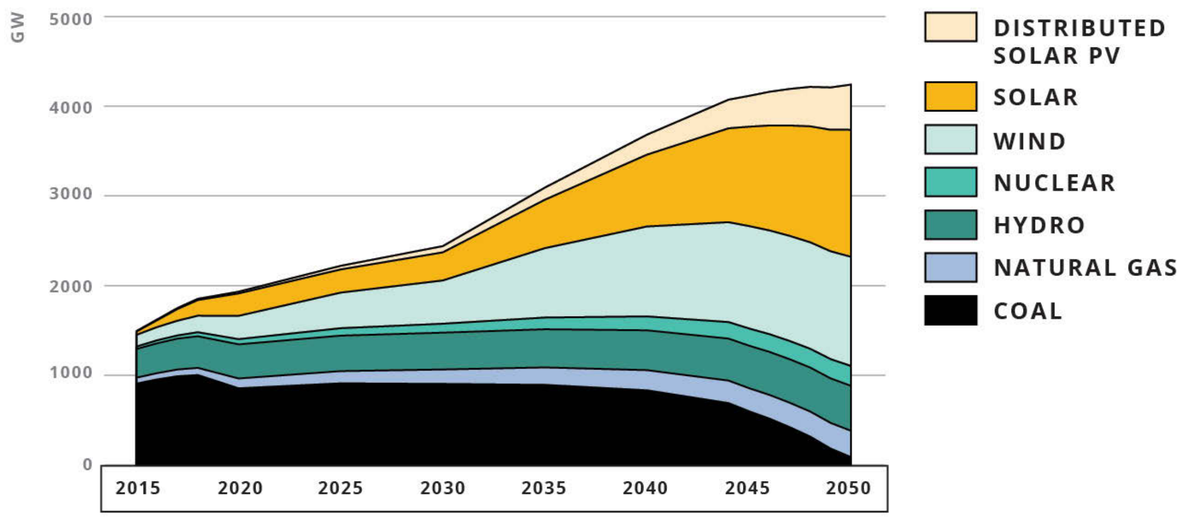

Figure 3-4. China's Power Generation Installed Capacity, China Energy Outlook's 2050 Continuous Improvement Scenario (2015-2050)
Note: China's geothermal installed capacity in 2018 was approximately 28 MW.

Similarly, generation from renewables and other non-fossil fuels replaces thermal generation in the China Energy Outlook's 2050 Continuous Improvement scenario. The model follows environmental merit dispatch that prioritizes non-fossil generation before fossil generation, and assumes recent stated policies on green dispatch will be fully implemented. By 2050, coal generates 470 TWh and natural gas generates about 540 TWh out of more than 9500 TWh[24] total. Generation from wind and solar in 2050 is about 20 times that in 2015; the share of wind and solar generation of total power generation grows from 4% in 2015 to nearly 50% in 2050 (Figure 3-5). Including hydro, nuclear, and distributed solar PV, non-fossil electricity sources generate 89% of China's electricity in 2050, more than triple the 2015 level (Figure 3-6).

[24] Recent policies prioritizing non-fossil generation included State Council's 2007 *Detailed Rules for Implementing Energy Saving Generation Dispatch*, 2015 *Opinions Regarding Further Deepening of Power Sector Reform* and national commitment to adopt "green dispatch" policy in June 2015.

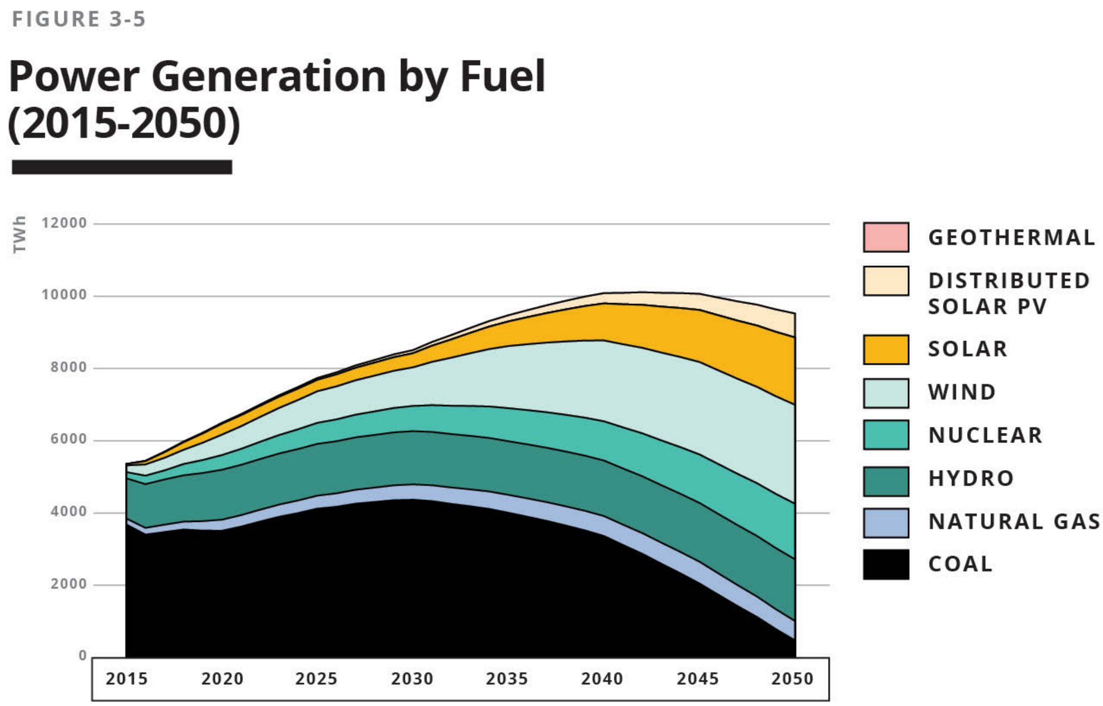

Figure 3-5. China's Power Generation by Fuel, China Energy Outlook's 2050 Continuous Improvement Scenario (2015-2050)

Note: In 2018, geothermal power generation is estimated to total only 0.3 TWh.

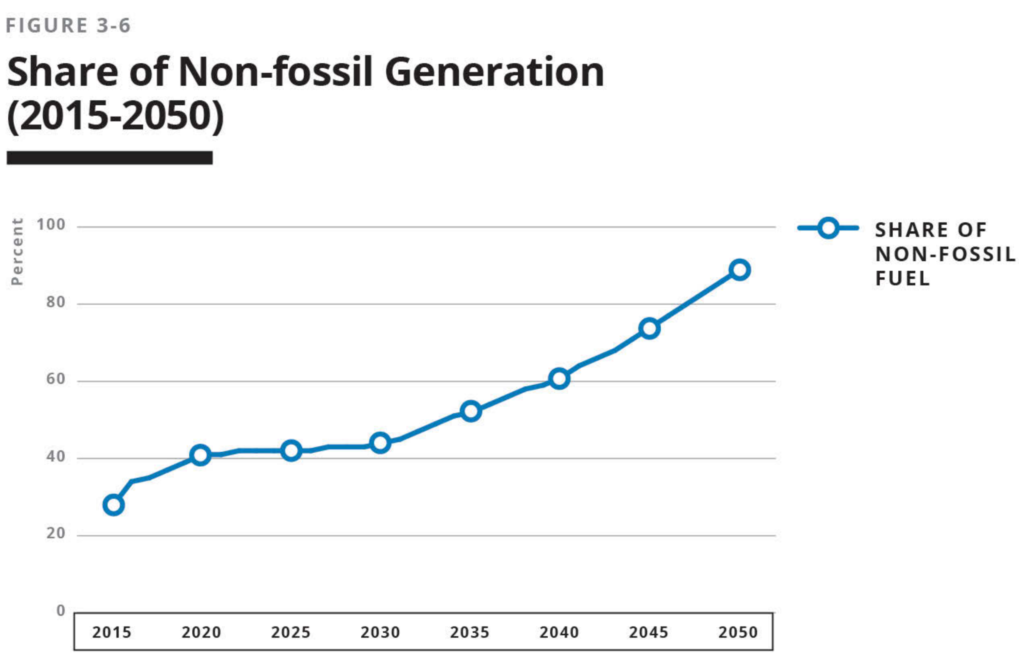

Figure 3-6. Decarbonization of China's Power System (2015-2050)

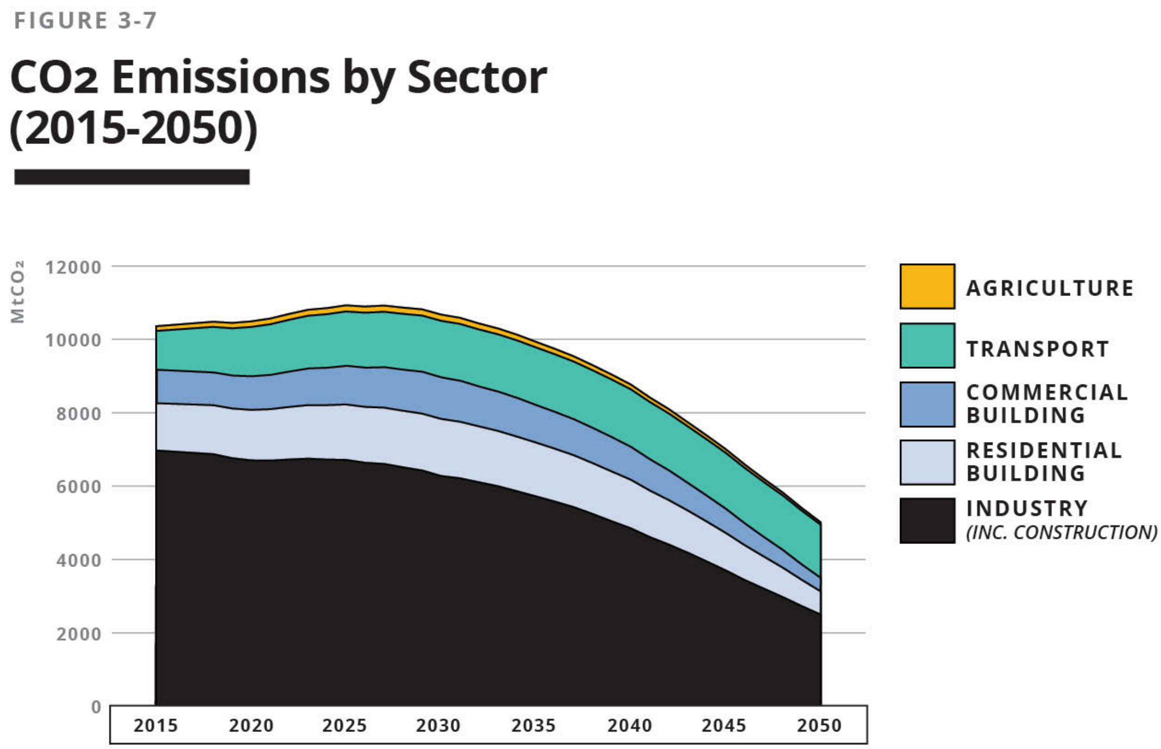

Figure 3-7. China's Energy-Related CO_2 Emissions by Fuel, China Energy Outlook's 2050 Continuous Improvement Scenario (2015-2050)

With energy efficiency and fuel switching (especially electrification) in the energy end use sectors and decarbonization of the power system, China's CO_2 emissions peaks in 2025 at a level of 10,930 $MtCO_2$ in the China Energy Outlook's 2050 Continuous Improvement Scenario. By 2050, China's total CO_2 emissions decrease to 5,010 $MtCO_2$, about 52% lower than 2015 levels (Figure 3-7).

In the China Energy Outlook's 2050 Continuous Improvement scenario, CO_2 emissions from the industry sector peaks before 2019 (see Figure 3-8).[25] The industrial sector share of total CO_2 emissions continues to decrease, from 67% in 2015 to 50% by 2050. The decline in industrial CO_2 emissions is linked directly to fuel switching from coal toward cleaner fossil fuels and electrification, as well as structural shift of production towards high value-added, less energy-intensive industries.

[25] Note that this modeling simulation result was based on model calibration to the latest available data, including energy balance data through 2015 and industrial production data up through 2017. Due to recent stimulus-related increases in industrial production and the time lag in national statistics reporting, particularly at the sectoral level, this finding may need to be revisited when full-year 2019 data are available.

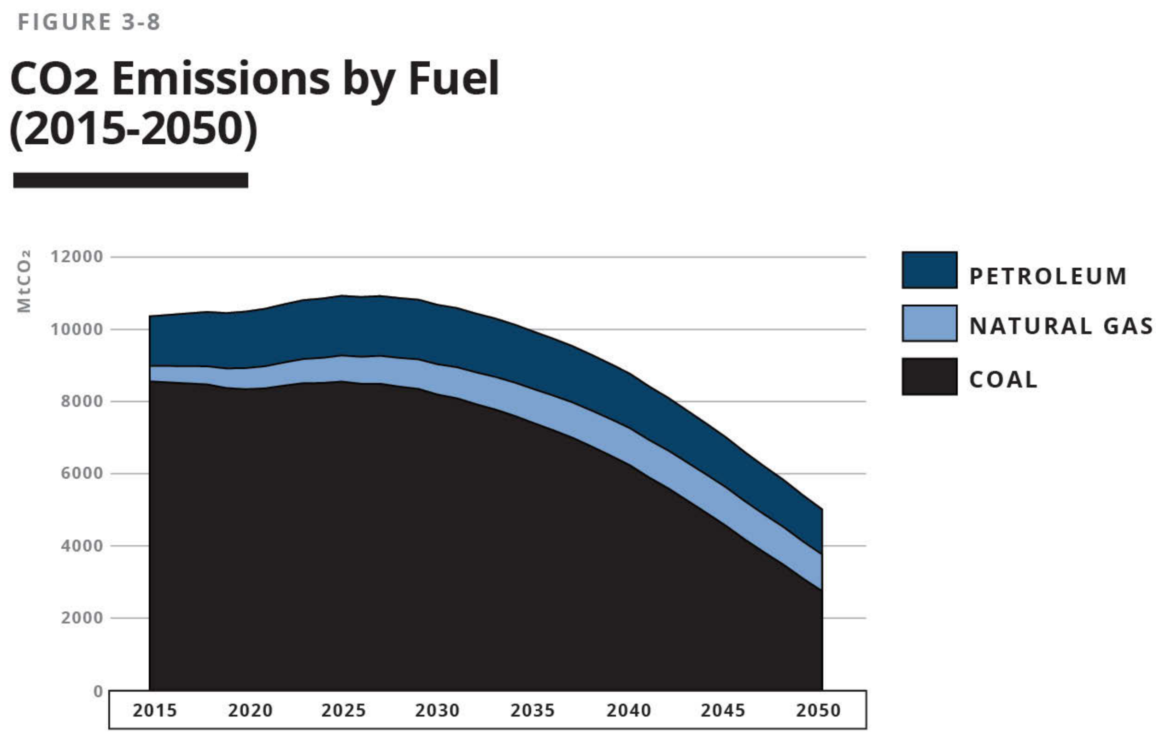

Figure 3-8. China's Energy-Related CO_2 Emissions by Sector, China Energy Outlook's 2050 Continuous Improvement Scenario (2015-2050)

CO_2 emissions from the transportation sector peak by 2035, but its share of total CO_2 emissions grows from 11% in 2015 to 28% in 2050. Growth in transport CO_2 emissions is driven by rapid increase in demand for freight transport and its continued reliance on fossil fuels, while the growth in passenger transport demand is partially offset by electrification coupled with an increasingly decarbonized power system.

For the building sector, CO_2 emissions peaks around 2030, but its share of total CO_2 emissions does not decline until 2045. In 2050, the share of CO_2 emissions from the building sector is 21%, the same level as in 2015. Continued efficiency improvement across all building end-uses, rapid fossil fuel switching for heating, a major energy consuming end-use, and rapid electrification of the building sector all contribute to the decline in building CO_2 emissions.

FIGURE 3-9

Industry Final Energy Consumption by Sector (2015-2050)

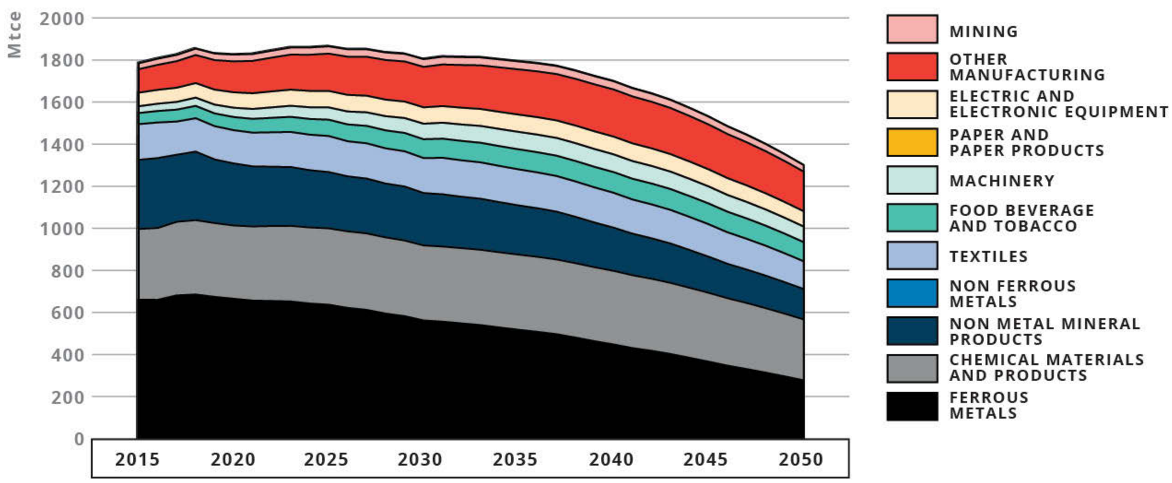

Figure 3-9. Industry Final Energy Consumption by Sub-sector, China Energy Outlook's 2050 Continuous Improvement Scenario (2015-2050)

Industry final energy consumption peaks by 2025 in the China Energy Outlook's 2050 Continuous Improvement Scenario, about ten years earlier than other end-use sectors, such as residential and commercial buildings (see Figure 3-9). After 2025, industry final energy consumption declines slightly at about 0.4% per year between 2025 and 2035. Industry final energy consumption decreases more sharply, at about 2% per year, between 2035 and 2050. This decrease can be traced back to reductions in the heavy, energy-intensive industries as a result of structural shift, a slowdown in domestic demand for heavy industrial products such as steel and cement, and significant improvements in energy efficiency reaching advanced economies' efficiency levels today. Energy use by the ferrous metals (e.g., crude steel) industry decreases significantly, from contributing 37% of industry final energy use in 2015 to 21% in 2050. Energy use in non-metal mineral products (e.g., cement) industry decreases as well, dropping from 18% in 2015 to 11% in 2050. The slowdown in both of these heavy industries can be linked in large part to the slowdown in construction and infrastructure development as population growth plateaus in the 2030s and urbanization slows. The share of chemical materials and products industry increases from 19% to 22% due to increased short-term demand for plastic products as population growth continues through 2030, but its absolute amount of energy use decreases due to slowdown in all chemical production activity after 2030 and to efficiency gains. The shares of other subsectors, such as textiles, food and tobacco sectors also increase, but the absolute amount of energy use decreases by 2050 primarily due to efficiency gains. At the same time, final energy use of subsectors such as machinery and electric and electronic equipment increases at about 2% and 1% per year, respectively.

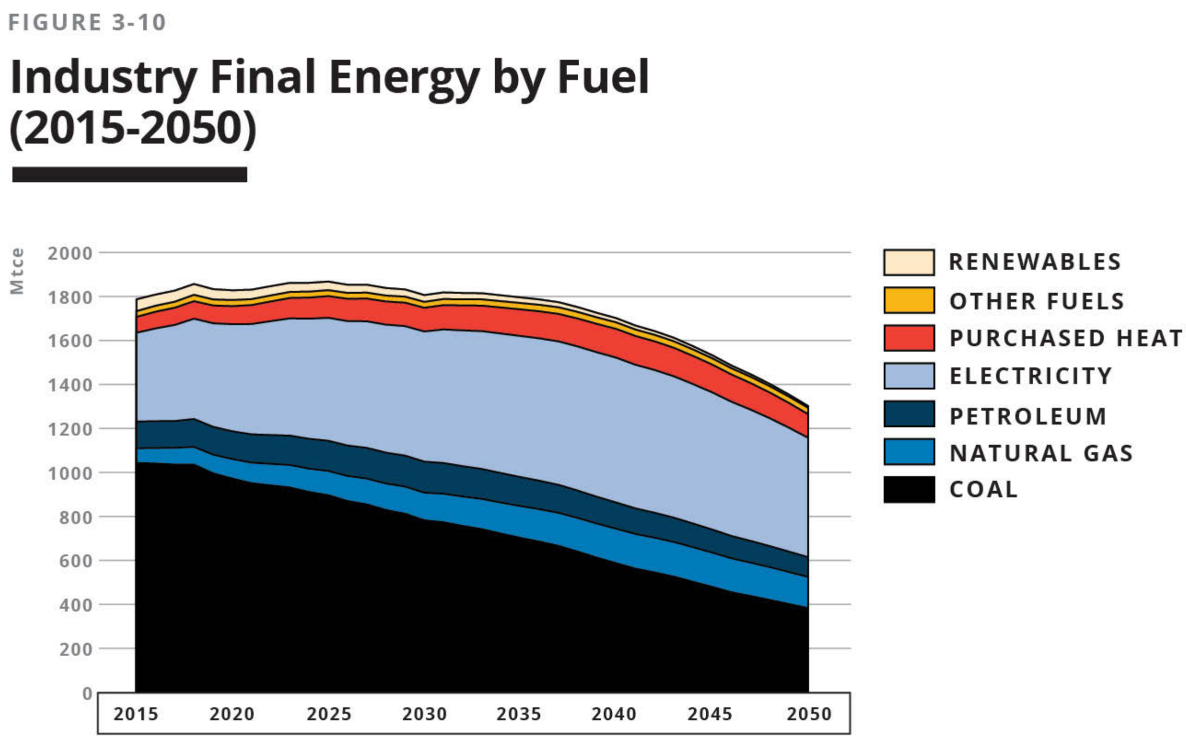

Figure 3-10. Industry Final Energy Consumption by Fuel, China Energy Outlook's 2050 Continuous Improvement Scenario (2015-2050)
Note: other fuels include coal gas and coking products.

In the China Energy Outlook's 2050 Continuous Improvement Scenario, industry final energy consumption peaks by 2025, but the decline of the direct use of fossil fuels in industry begins earlier, at around 2015 for coal and 2018 for petroleum (Figure 3-10) as a result of fuel switching and increased electrification of industrial processes, particularly for the manufacturing subsectors. The use of natural gas in industry continues to increase, and won't decline until 2042. Coal consumption in industry decreases sharply, from a decline of 2% per year between 2015 and 2025, and further to a decrease of 3% per year between 2025 and 2050. The share of coal use in industry will decrease from 48% in 2015 to 30% in 2050. The share of electricity consumption in industry increases from 30% in 2015 to 43% in 2050. The absolute amount of electricity consumption also increases, with a peak of electricity consumption in industry at around 2040, and declines slowly through 2050. The use of purchased heat peaks at around 2040 as well.

Building sector energy use is driven by China's continuous urbanization and people's increasing demand for better indoor comfort and better building services. Population in cities will increase from 0.7 billion in 2015 to 1.1 billion in 2050. China's urban per capita living floor space will increase from 35m^2/person in 2015 to 46m^2/person in 2050. Similarly, for commercial buildings, the tertiary sector employee number and per employee floor space will increase from 413 million and 33 m^2/person in 2015 to 475 million and 45 m^2/person in 2050, respectively. Thus, building floor space will continuously increase over time. Per floor space, energy demand will also increase because of improving living standards. The cooling demand in residential and commercial buildings will increase drastically from 2015 to 2050 across all different climate zones in China. Heating load will also increase, especially in China's transition climate zone (the "Hot Summer Cold Winter" climate zone), due to the absence of district heating in that area in the past and an increasing demand for improved thermal comfort in wintertime.

To control the sharp energy demand increase in the building sector, a series of energy efficiency measures and policies are taken into consideration in the China Energy Outlook's 2050 Continuous Improvement Scenario. All new construction needs to meet the current national and local energy efficiency standards requirements. The China Energy Outlook's 2050 Continuous Improvement scenario assumes that China will take significant efforts to demonstrate and build ultra-low (or nearly zero) energy buildings, particularly in Northern China where heating loads are the greatest. In Northern China, the scenario assumes that the ultra-low energy new construction rate will increase from 0% in 2015 to 50% of the annual new construction in 2050, compared to lower rates of 20% in the transition and 10% in the southern climate zones. Retrofitting existing buildings is also important to improve the thermal integrity of buildings, particularly for heating. The China Energy Outlook's 2050 Continuous Improvement Scenario assumes that 75% of the entire country's existing building stock built before 2010 will be retrofitted in 2050, with a greater share of deep retrofits in Northern China where heating demand is highest. Today's cost-effective, high efficiency appliances will be gradually adopted and increase to 100% adoption rate in 2050. Heating and cooling technology efficiency will be improved in buildings. The average energy efficiency for district heating will increase from current 69% to 81%. Air-conditioning energy efficiency will increase by 42% based on its 2010 level.

Residential final energy consumption continues to rise through 2040, when it peaks under the China Energy Outlook's 2050 Continuous Improvement Scenario (Figure 3-11). Growth in final energy consumption slows after 2025, from an annual growth rate of 2.4% from 2015 to 2025, to only 1.0% from 2025 to 2035. Future growth in residential energy consumption is driven mainly by growing urban residential demand for cooling, appliances, cooking, and water heating (Figure 3-12). Growth in demand for heating and cooling energy services is offset by significantly improved building design for new buildings, including passive and near zero energy design, and deep retrofits that dramatically improve building shell and insulation. Despite efficiency improvements, appliances, and cooking and water heating energy use continues to grow through 2050 as their usage loads are expected to increase with rising household incomes and living standards. Rural residential energy demand peaks in 2020, 20 years earlier than urban residential energy demand, as a result of the continued shift of residents from rural to urban households.

FIGURE 3-11

Residential Final Energy Consumption by End-Use (2015-2050)

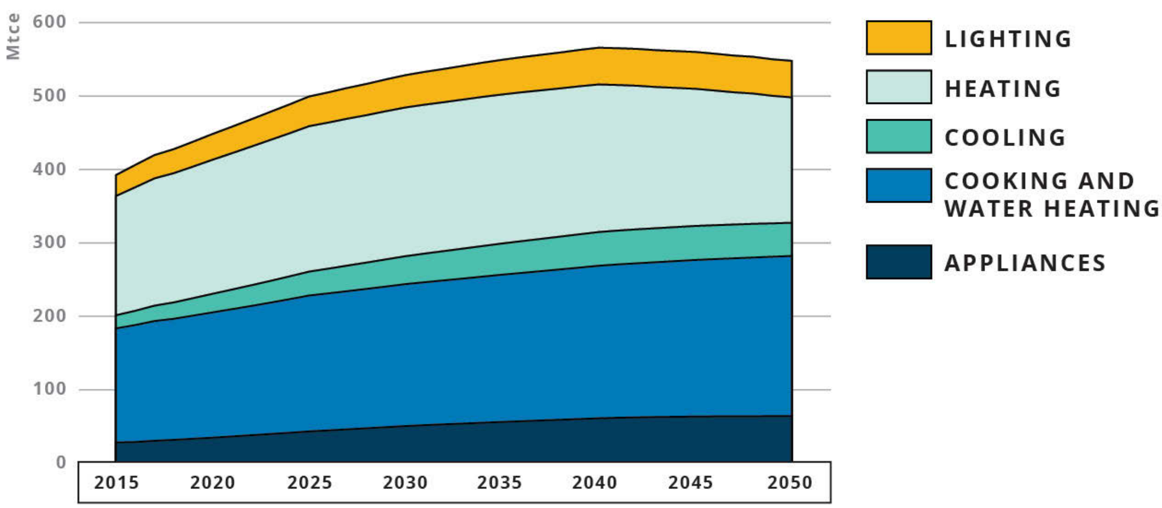

Figure 3-11. Residential Buildings Final Energy Consumption by End-Use, China Energy Outlook's 2050 Continuous Improvement Scenario (2015-2050)

FIGURE 3-12

Rural & Urban Residential Buildings Final Energy Consumption by End-Use (2015-2050)

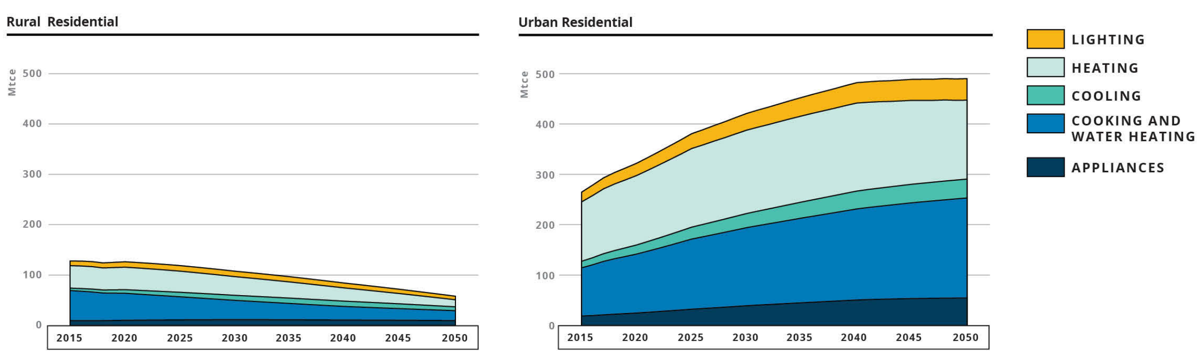

Figure 3-12. Urban and Rural Residential Buildings Final Energy Consumption by End-Use, China Energy Outlook's 2050 Continuous Improvement Scenario (2015-2050)

In the China Energy Outlook's 2050 Continuous Improvement Scenario, commercial building final energy consumption grows very rapidly through 2030 at an average rate of 3.5%. Between

2030 and 2039, when total final energy consumption peaks, growth in commercial building energy consumption begins to slow to an average rate of 0.9% per year. Equipment and water heating energy consumption continues to rise through 2050, with its share of total energy consumption rising from 10% and 13% in 2015, respectively, to 25% and 15%, respectively, in 2050 (Figure 3-13). Energy consumption by the other end-uses of heating, cooling, and lighting begins declining in the late 2030s.

FIGURE 3-13

Commercial Building Final Energy Consumption by End-Use (2015-2050)

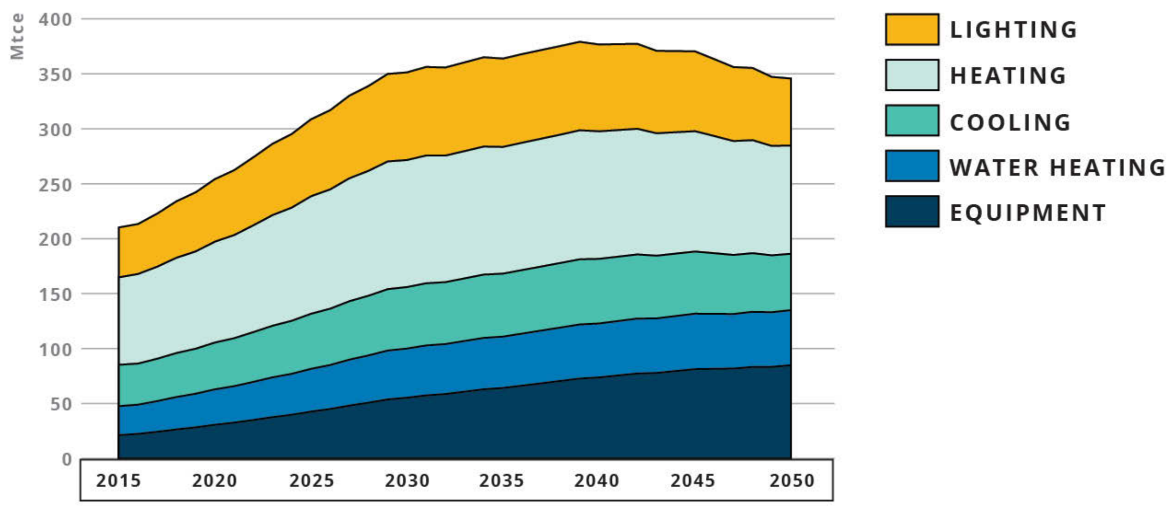

Figure 3-13. Commercial Buildings Final Energy Consumption by End-Use, China Energy Outlook's 2050 Continuous Improvement Scenario (2015-2050)

Note: Commercial building equipment includes all commercial building plugloads such as office equipment and other building operating equipment such as elevators and refrigeration.

An important way to reduce building sector CO_2 emissions is to switch fossil fuel-based energy end use to electricity. As the electric grid in China integrates more and more clean energy leading to a decrease of per kWh emission factors over time, electrification of building energy end use can greatly reduce CO_2 emissions in the building sector. In the China Energy Outlook's 2050 Continuous Improvement Scenario, we considered electrification through increased use of electric heat pumps for space heating and for water heating, and electric stoves for cooking. At the same time, rural coal-based space heating is replaced by electric heating and all coal-based cooking will also be replaced.

Although the transport of freight around China is expected to more than triple in terms of tonne-kilometers (tkm) between 2015 and 2050 in tandem with continued growth of the economy, energy consumption for freight transport is expected to rise more modestly in the China Energy Outlook's 2050 Continuous Improvement scenario. The increase is about 36% over this period (Figure 3-14). This is primarily due to continued increases in the operational efficiency of each mode of travel, in particular for trucks, which will decrease fuel use per tkm by about 40% compared to current levels. In addition, improved truck logistics allows reductions in empty loads, thus increasing total tkm per truck as well. Spurred by an already high level of oil import dependence, an increasing number of trucks have been converted to run on LNG, and this trend will continue throughout the period with natural gas's share of freight final energy consumption rising from a mere 3% in 2015 to 25% in 2050 (Figure 3-14). Petroleum's share of freight energy consumption, in contrast, peaks around 2025 and declines thereafter as a result of gradual fuel switching towards LNG and some plug-in diesel hybrids, but still accounts for 68% of freight energy consumption by 2050. Diesel, jet kerosene, and fuel oil are the major petroleum products consumed. In the China Energy Outlook's 2050 Continuous Improvement scenario, emerging alternatives such as battery electric vehicle (EV) trucks or hydrogen fuel-cell trucks are not seen, although studies to assess their potential are ongoing.

FIGURE 3-14

Freight Transport Final Energy Consumption by Fuel (2015-2050)

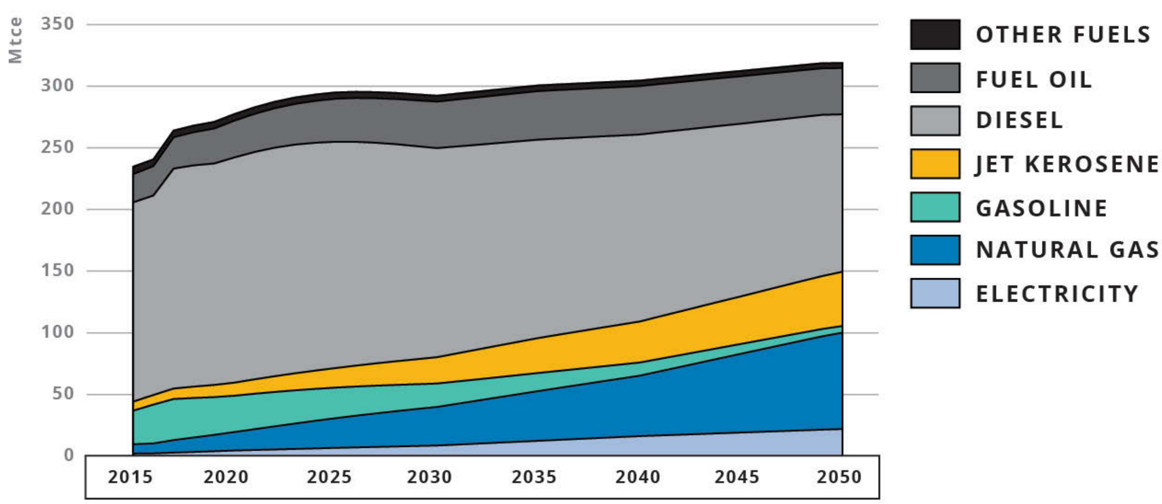

Figure 3-14. Freight Transport Final Energy Consumption by Fuel, China Energy Outlook's 2050 Continuous Improvement Scenario (2015-2050)

Given the already high efficiency of both water and rail as modes for freight transport, reliance on both will continue to expand, along with continued electrification of the rail system, which will serve to further reduce emissions as the power system continues to decarbonize (Figure 3-15). Air freight is fairly energy intensive per tkm hauled, but growth in rapid delivery demand will increase its share of energy consumption over time from 3% in 2015 to 14% in 2050.

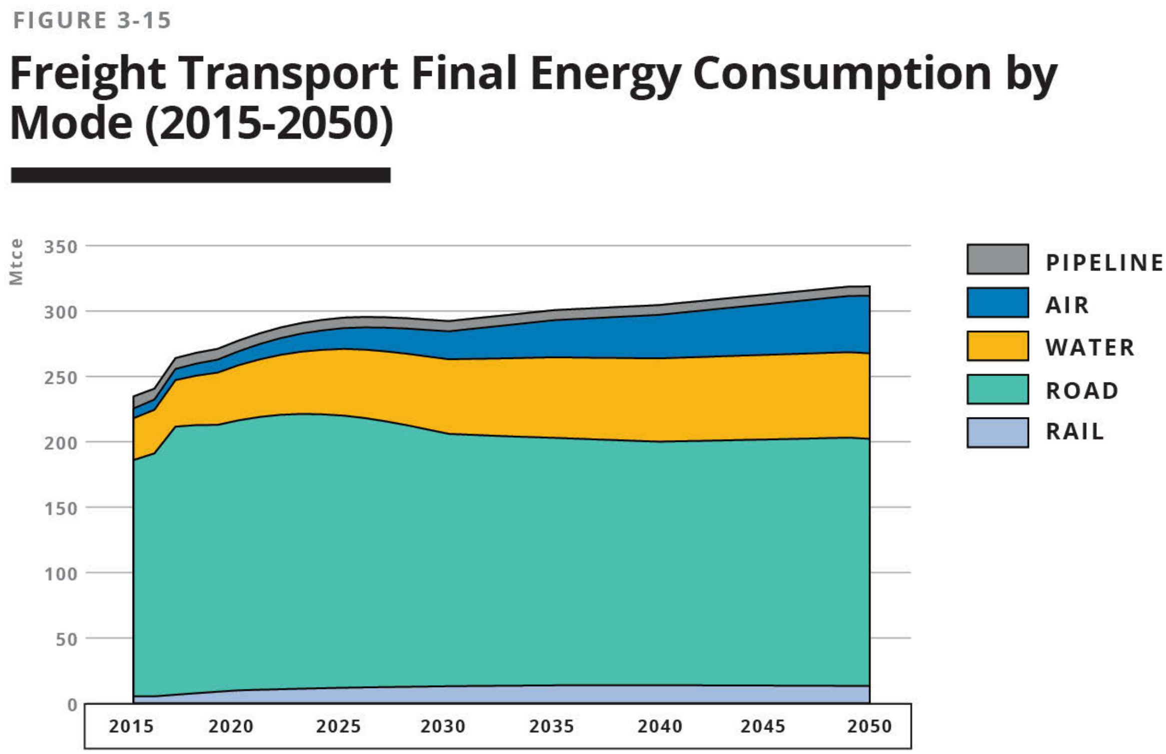

Figure 3-15. Freight Transport Final Energy Consumption by Mode, China Energy Outlook's 2050 Continuous Improvement Scenario (2015-2050)

Passenger transport is driven primarily by increased urbanization and increased household wealth translating into increased demand for mobility, particularly for private transport. Electricity will increase its share of total passenger transportation energy use to 15% by 2050 as the share of EVs rises to 38% of the total private car fleet and 22% of urban bus fleet (Figure 3-16). But petroleum, mainly gasoline, jet kerosene, and some diesel, will remain the dominant fuel in use, even with a 60% decrease in the fuel intensity of internal combustion engine (ICE) vehicles and nearly 30% decrease in fuel intensity of airplanes over the period. Natural gas, in the form of CNG, will also increase over time, mainly for buses.

FIGURE 3-16

Passenger Transport Final Energy Consumption by Fuel (2015-2050)

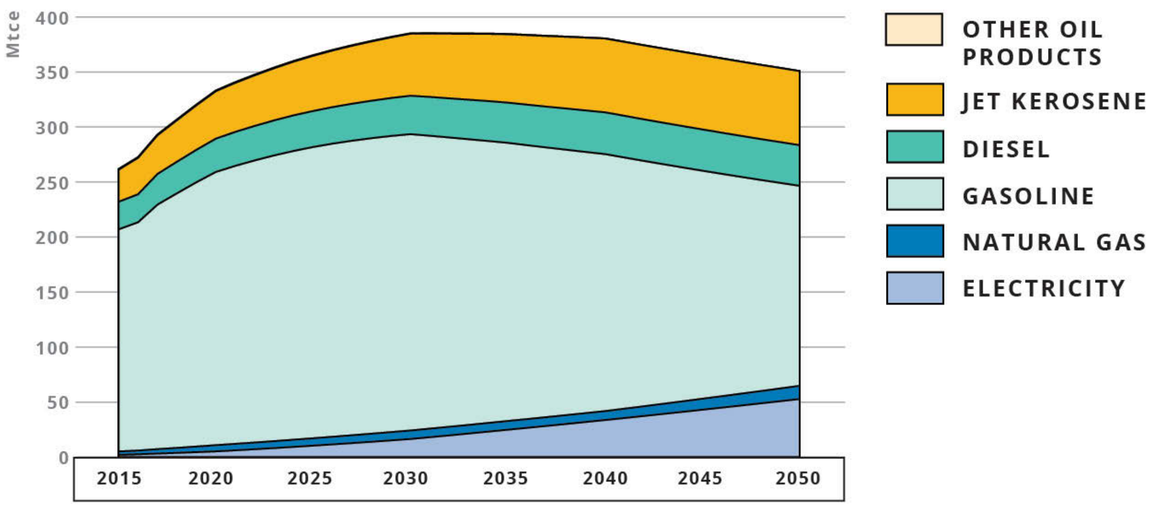

Figure 3-16. Passenger Transport Final Energy Consumption by Fuel, China Energy Outlook's 2050 Continuous Improvement Scenario (2015-2050)

Under the China Energy Outlook's 2050 Continuous Improvement Scenario, the primary provider of personal mobility will remain the personal automobile, but over the scenario period, the predominance of ICE vehicles will give way to a steady increase in all-EVs. China is currently discussing the idea of ending the sale of ICEs in favor of EVs, but no timeline has been set. Even with an end to new ICE sales, it will take some time for the existing fleet of ICEs to disappear absent directed policies to accelerate the transition. Road travel will account for the majority of kilometers traveled with steady increases in both air and rail travel (Figure 3-17). By 2050, road travel will still account for 79% of total passenger transport energy consumption, versus 19% for air and 2% for rail. Unlike in other large countries such as the U.S., it is expected that Chinese travelers will largely forego air travel for distances less than 750 km owing to the extensive build-out of the high-speed rail network. Even so, the relative inefficiency of air travel leads to a doubling of energy use—all petroleum—for flying.

FIGURE 3-17

Passenger Transport Final Energy Consumption by Mode (2015-2050)

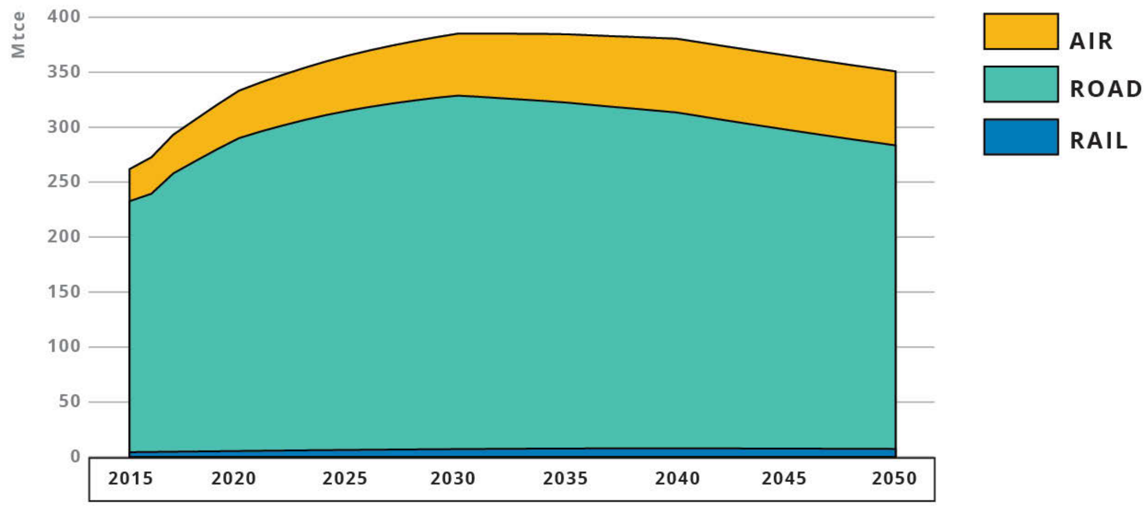

Figure 3-17. Passenger Transport Final Energy Consumption by Mode, China Energy Outlook's 2050 Continuous Improvement Scenario (2015-2050)

Comparison of China Energy Outlook's 2050 Continuous Improvement Scenario to Other China Outlooks

How do the future projections of energy use and energy-related emissions in this China Energy Outlook compare to those of other international and China-based organizations that analyze China's future? This section compares the key findings of the China Energy Outlook's 2050 Continuous Improvement Scenario to similarly defined scenarios from the following studies from international and China-based organizations:

International

- International Energy Agency (IEA, 2019e)
- BP (BP, 2019c)
- ExxonMobil (ExxonMobil, 2019)
- Bloomberg New Energy Finance (BNEF, 2019)

China-Based

- China National Renewable Energy Center (CNREC, 2018)
- State Grid Energy Research Institute (SGERI, 2019)
- China National Petroleum Corporation Research Institute of Economics and Technology (CNPC, 2018)
- China Petroleum & Chemical Corporation (Sinopec) (Sinopec, 2019)
- China Energy Research Institute (Jiang et al., 2018)

The relevant scenarios from the recent modeling studies published by these international and China-based research organizations are summarized in Table 3-2. We compared the high-level results in terms of total primary energy consumption outlook, CO_2 outlook, and non-fossil share of electricity generation among the major studies based on available data.

Table 3-2: Summary of International and China-Based Modeling Studies

Organization	Scenario Name	Scenario Period
Lawrence Berkeley National Laboratory	China 2050 Continuous Improvement Scenario	2015-2050
International Energy Agency	Stated Policies	to 2040
BP	Evolving Transition	2017-2040
ExxonMobil	N/A	to 2040
Bloomberg New Energy Finance	N/A	to 2050
China National Renewable Energy Center	Stated Policies	2017-2050
China National Petroleum Corporation Research Institute of Economics and Technology	Reference	to 2050
State Grid Energy Research Institute	Normal Transition	to 2050
China Petroleum & Chemical Corporation (Sinopec)	N/A	to 2050
China Energy Research Institute	Low Carbon Scenario	to 2050

Primary Energy Use Scenario Comparison

Comparing the China Energy Outlook's 2050 Continuous Improvement Scenario to other similarly defined scenarios published in other recent studies shows similarity in the range of the projected future primary energy use up to 2030, but with markedly different trends in the later years through 2050 (Figure 3-18).[26] Between 2010 through 2035, the China Energy Outlook's 2050 Continuous Improvement Scenario falls within the range of other projected primary energy use of between a low of 3280 Mtce in 2010 to a high of nearly 5400 Mtce in the peak year of 2029.

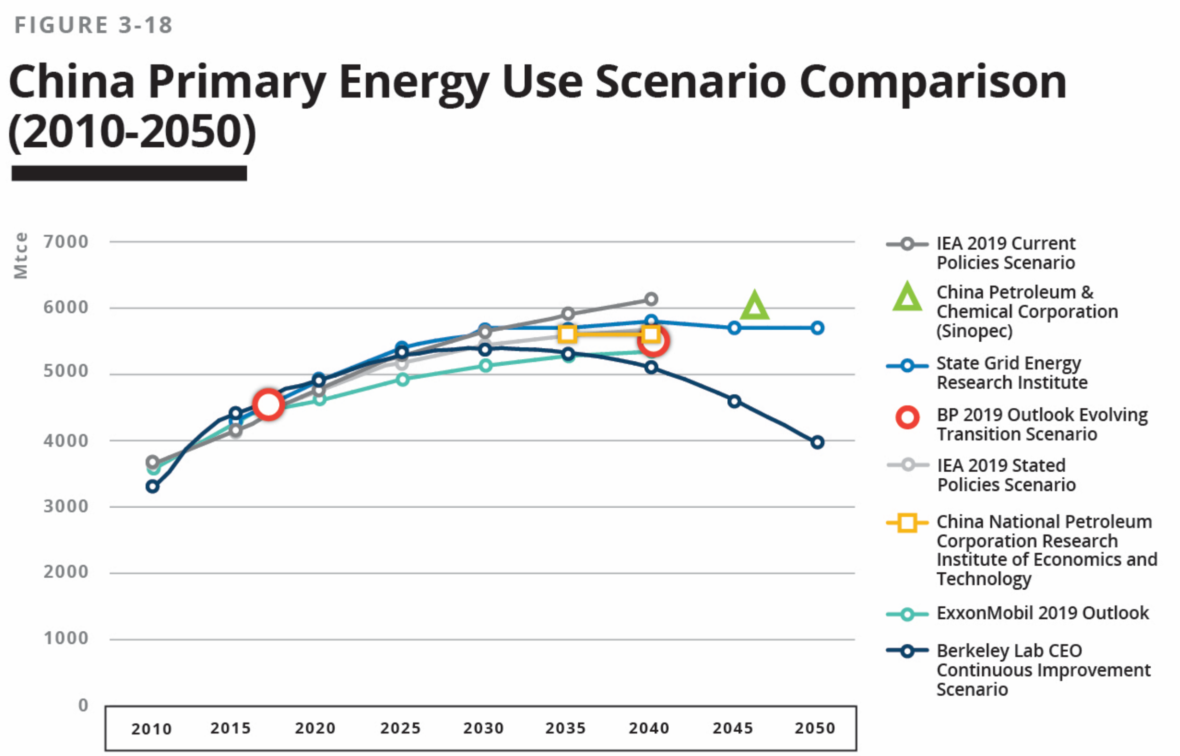

Figure 3-18. Comparison of Primary Energy Use Projections by Scenario

Note: Annual data points for other projections are interpolated between published milestone values. Primary energy use totals have not been normalized to account for differences in converting non-fossil electricity generation into primary energy equivalent.

Berkeley Lab's China Energy Outlook 2050 Continuous Improvement Scenario's projected primary energy use has a notably different shape than other projections, with plateauing in the mid-2025s, a peak in 2029, and significant declines thereafter. While the State Grid outlook also shows a peak in energy use of around 5650 Mtce in 2030 and general plateauing thereafter and the China National Renewable Energy Center projects an unspecified primary energy use peak

[26] We have not attempted to normalize primary energy use totals to account for differences in conversion methods for converting non-fossil electricity generation into primary energy equivalent due to incomplete information and data from some studies.

in 2025, none of the other similar scenarios by the other organizations show a marked decline in energy use prior to 2050. Given the similar starting point and close range in projected energy use in the early 2020s, this divergence in trend is likely due to accounting for saturation effects in consumption, ownership, construction and thus industrial activity as the population peaks in 2030 and begins to decline, along with a combination of more aggressive efficiency and fuel switching, as well as accounting of more saturation effects in the China Energy Outlook's 2050 Continuous Improvement Scenario.

CO_2 Emissions Scenario Comparison

In terms of energy-related CO_2 emissions, CREO 2018's Stated Policy Scenario has the earliest CO_2 peak projected for 2020, at a level consistent with projected CO_2 emissions for 2020 by the China Energy Outlook and State Grid's Outlook. The IEA, ExxonMobil, State Grid, and China Energy Outlook all project a CO_2 emissions peak for China in 2025 under their scenarios, albeit at differing peak levels (Figure 3-19). The China Energy Outlook's Continuous Improvement Scenario's CO_2 emissions peak level of 10.9 $GtCO_2$ is the highest amongst the four 2025 projected CO_2 peaks[27], slightly higher than State Grid's projected peak of 10.7 $GtCO_2$, and much higher than ExxonMobil Outlook's projected CO_2 peak of 9.6 $GtCO_2$. Sinopec also finds a peak before 2030 (with unspecified year) in their outlook, with a peak level in the mid-range of other projected 2025 emission peaks. China's Energy Research Institute finds a peak in 2030 around 11 $GtCO_2$, followed by a plateau thereafter, under their Low Carbon scenario.

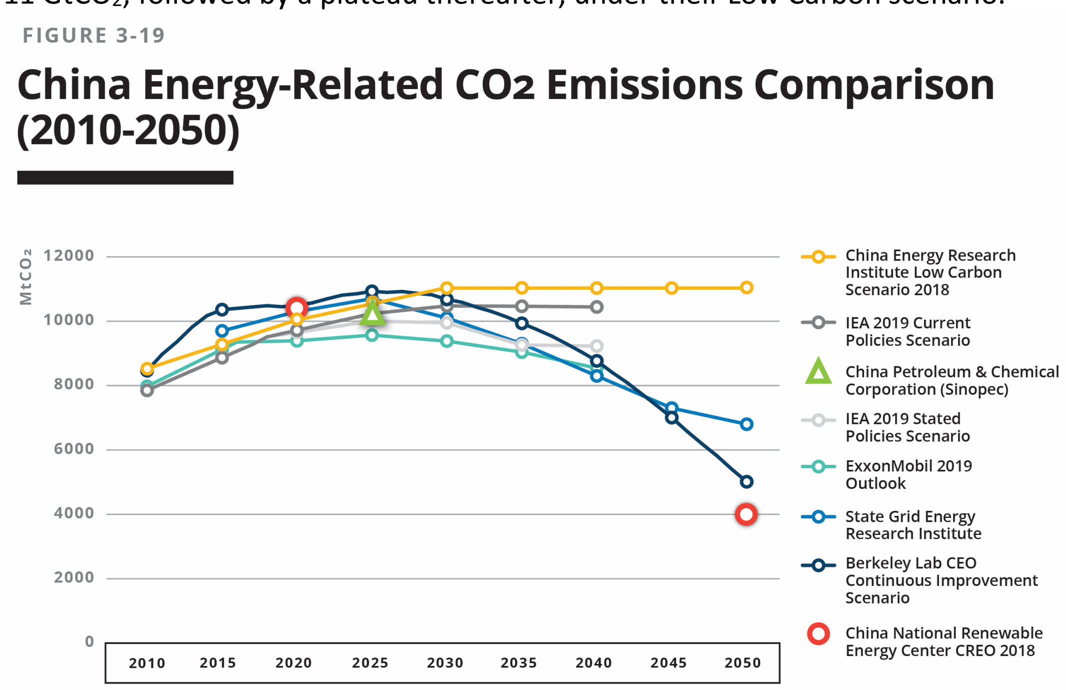

Figure 3-19. Comparison of Energy-Related CO_2 Emissions Projections by Scenario

Note: Annual data points for other projections are interpolated between published milestone values.

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[27] The higher emissions peak of CEO is likely due to accounting differences that lead to differing 2010 starting points.

Post-peak projections of CO_2 emissions differ between two main groups of studies. The China Energy Outlook, the State Grid, and CREO 2018 find rapid decline in CO_2 emissions after 2030 while IEA, ExxonMobil, and ERI project general plateauing with slow declining emissions after their projected 2025 peaks. While China Energy Outlook and State Grid's 2025 CO_2 emission peak is more than 1 Gt higher than IEA and ExxonMobil's CO_2 peaks, both Outlooks' projected CO_2 emissions reach virtually the same level as IEA and ExxonMobil by 2038. But by 2050, the China Energy Outlook's Continuous Improvement Scenario's and CREO 2018's projected baseline CO_2 emissions are much lower than the State Grid's projected 2050 CO_2 emissions, despite similar levels in 2020 and peaking levels in 2025.

Non-Fossil Power Generation Share Comparison

The projected non-fossil share of total power generation in 2025 and 2030 are very similar between the China Energy Outlook's 2050 Continuous Improvement Scenario, the two IEA scenarios, and the ExxonMobil outlook, ranging from 36% to 42% in 2025 and 38% to 43% in 2030 (Figure 3-20). In 2030, the China Energy Outlook's 2050 Continuous Improvement Scenario and IEA Stated Policies Scenario have virtually the same projected non-fossil power generation share of 43%. In 2035, the China Energy Outlook's 2050 Continuous Improvement Scenario's non-fossil generation share is lower than State Grid's projected 60%. But by 2040, the China Energy Outlook's 2050 Continuous Improvement Scenario forecasts a much higher non-fossil power generation share than the IEA and ExxonMobil outlooks, with a 10 percentage point higher share than both the IEA Stated Policies Scenario and the ExxonMobil Outlook. Similarly, the China Energy Outlook's 2050 Continuous Improvement Scenario's 2050 non-fossil generation share of 92% is also much higher than State Grid's baseline non-fossil generation share of 78%.

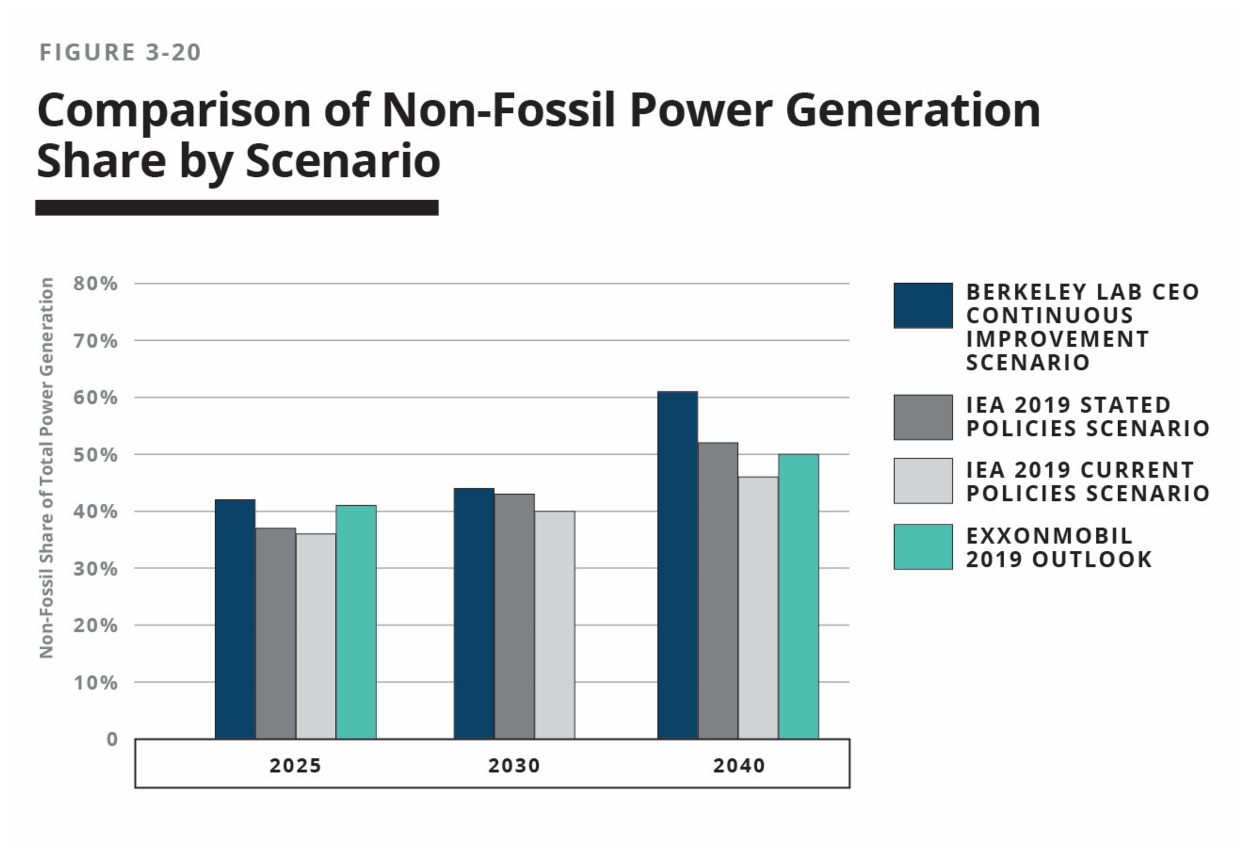

Figure 3-20. Comparison of Non-Fossil Power Generation Share by Scenario

To provide more context for understanding the high-level energy and CO_2 results of the other modeling studies, a summary of each study and its key findings is presented below and also summarized in Appendix 3.

International Energy Agency (IEA): 2019 World Energy Outlook

The IEA publishes its *World Energy Outlook* (WEO) report annually with its energy and emissions scenario outlook for the world using its global World Energy Model. In its 2019 WEO, the IEA included a detailed focus on its China Energy Outlook out to 2040 for its three scenarios, the Current Policies Scenario that only considers existing policies and measures as of mid-2019, the Stated Policies Scenario and the more ambitious Sustainable Development Scenario (IEA, 2019e). Similar to Berkeley Lab's China Energy Outlook 2050 Continuous Improvement Scenario, the WEO's Stated Policies Scenario considers all current policies as well as planned policies and targets announced by governments, including the Nationally Determined Contributions for the Paris Agreement. The scenario outlooks for China and scenario names were updated in the 2019 WEO, but the scenario definitions remain the same.

Under the Stated Policies Scenario, IEA finds that China's primary energy consumption[28] continues to grow but at a slower pace between 2030 to 2040, growing from 5441 Mtce in 2030 to only 5680 Mtce in 2040. In terms of fuel mix, electricity replaces coal and oil as the main source for energy consumption by 2040, representing 35% of total final energy consumption, followed by oil and coal, which accounts for 26% and 16% of total final energy consumption, respectively. From an end-use perspective, industry and building sectors remain key drivers of energy demand, particularly for electricity, and together accounts for 68% of energy consumption in 2040. Industry sector's share declines to 43% in 2040, while building sector energy consumption continues to grow due to growth in residential building floorspace and higher energy demand for heating, cooling, and appliance usage. As a result of fuel switching, energy-related CO_2 emissions peak by 2025 at 10.0 billion tons of CO_2.

BP: BP 2019 Energy Outlook

BP publishes its global energy outlook annually. This is used to aid corporate analysis and decision-making, and includes a China-specific outlook through 2040. Its 2019 *Energy Outlook*, the Evolving Transition (ET) scenario, which assumes that government policies, technology and social preferences continue to evolve in a manner and speed seen over the recent past, contains a baseline scenario as well as alternative side scenarios focused on specific policies or fuels (BP, 2019c).

Under the ET scenario, China's GDP will grow at an average rate of 4.6% per year from 2017 to 2040, compared to energy demand growth at an average rate of 1.1% to 2040. Total energy consumption will increase from 4,490 Mtce to 5,744 Mtce.[29] In terms of fuel mix, rapid growth in natural gas at 4.4% annually and non-fossil electricity at 5.1% annually will help displace coal consumption, which falls by 700 Mtce in 2040 compared to 2017 levels. By sector, the fastest growth is expected from buildings and transportation. Non-combust fuels for feedstock, including for plastics, is another major source of energy demand growth, at an average rate of 2.3% through 2040. Industrial energy consumption will remain relatively flat from 2017 levels, and account for half of total energy consumption by 2040. Under the ET scenario, China's CO_2 emissions are projected to peak as early as 2022.

ExxonMobil: 2019 Outlook for Energy

Similar to BP, ExxonMobil also publishes a global energy outlook that represents its view of energy demand and supply. It is used to inform long-term business strategies and investment planning. The outlook consists of only one scenario, which is based on likely trends in

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[28] IEA uses the physical energy content method for converting electricity generation into primary energy equivalent, and assumes 33% conversion efficiency for nuclear and solar thermal generation, 100% conversion efficiency for wind, solar photovoltaic, and tidal generation, and 10% conversion efficiency for geothermal generation.

[29] BP uses the substitution method for converting electricity generation into primary energy equivalent, and assumes 38% conversion efficiency (global average thermal power generation) for nuclear, hydro and renewable generation.

technology, policy, consumer preferences, geopolitics, and economic development, similar to a baseline scenario.

For China, the 2019 *Outlook for Energy* finds that primary energy consumption will see moderate growth out to 2040 at an average growth rate of 0.8%, reaching 5.1 Btce in 2030 and 5.3 Btce in 2040. This is much slower than the annual GDP growth rate of 4.7% expected through 2040, tripling of per capita GDP by 2040. China's energy-related CO_2 emissions is expected to peak at around 9.6 $GtCO_2$ in 2025, and gradually decline to 8.5 $GtCO_2$ by 2040. In the power sector, coal generation is assumed to remain relatively constant through 2040 but non-fossil share of total electricity generation will reach nearly 50% by 2040.

Bloomberg New Energy Finance (BNEF): New Energy Outlook 2019

Bloomberg New Energy Finance's *New Energy Outlook 2019* focuses specifically on the global electricity sector and includes a regional focus on China. It finds that China's coal generation and related emissions will peak in 2027, when renewables also reach 37% penetration share. By 2050, China is expected to have 1.3 TW of solar photovoltaic installed capacity, 1.2 TW of wind installed capacity, and 182 GW of nuclear installed capacity. In 2050, China's wind and solar will account for 48% of total electricity generation.

China Petroleum & Chemical Corporation (Sinopec): 2019 China Energy and Petrochemical Industry Development Report

China's oil and gas company, China Petroleum & Chemical Corporation (Sinopec), publishes an annual report on the status of national energy and petrochemical industry development as well as its own energy outlook for China. In the energy outlook in its 2019 annual report, Sinopec expects China's total primary energy consumption to peak at around 2045 with 6 Btce. Coal consumption will continue to decline and accounts for 34% of total primary energy consumption by 2050, nearly the same as non-fossil energy sources. Oil consumption will peak around 2030 with 720 million tons of oil, while natural gas consumption does not peak until 2050 with total consumption of 700 billion cubic meters. Refined oil demand will peak around 2027 at 370 million tons, and transportation fuel will gradually be replaced by petrochemical feedstock as the major refining product by 2050. Non-fossil energy sources will account for 35% of total primary energy consumption by 2050. In the power sector, non-fossil installed capacity will total over 2800 GW and generate 7300 TWh in 2050. China's CO_2 emissions will peak before 2030 at around 9.9 billion tons CO_2.

China National Petroleum Corporation Research Institute of Economics and Technology: World and China Energy Outlook to 2050, 2018 version.

China's largest major oil and gas corporation, the China National Petroleum Corporation (CNPC), publishes an annual *World and China Energy Outlook to 2050* under its Research Institute of Economics and Technology. In its 2018 Outlook, CNPC projects that China's primary energy consumption will plateau and peak between 2035 to 2040 at around 5.6 Btce under its Reference Scenario. By 2050, China's energy consumption per unit of GDP will reach a level similar to that of Japan in 2016, and one that is 74% lower than China's 2015 level. China's energy-related CO_2 emissions will peak between 2025 to 2030, consistent with China's NDC, and coal, oil and gas, and non-fossil fuels will all contribute equally to China's total energy supply by 2030. After 2030, natural gas consumption will continue to grow, driven by rising demand from industry, household, and power generation sectors and total demand will grow to 690 bcm by 2050. Oil demand is projected to peak around 2030 at 700 million tons, and oil used as feedstock will also increase, while transport fuel's share will decrease. In terms of end-use sectors, industrial energy consumption will peak by 2025 while energy consumption in transportation sector will plateau around 2030, and energy consumption in buildings sector will continue to grow slowly. By 2050, electricity will account for 38.5% of total final energy consumption.

State Grid Energy Research Institute: China Energy and Electricity Outlook 2018

In addition to the national energy outlooks published by China's two key oil and gas corporations, China's state-owned electric utility, State Grid, also publishes its *China Energy and Electricity Outlook* annually. The State Grid Energy Research Institute's *China Energy and Electricity Outlook 2018* includes a baseline scenario, the Normal Transition Scenario, and a more aggressive High Electrification Scenario that considers higher electrification rates, faster energy efficiency improvement, lower renewable and storage costs and a more flexible grid.

Under the Normal Transition Scenario, China's primary energy consumption peaks at around 5.80 Btce by 2040, and reaches current international advanced levels of energy consumption per unit of GDP by 2035. Electricity will surpass coal as the main energy form for meeting final energy demand by 2025, and non-fossil share of electricity generation will reach 60% by 2035 and 78% by 2050. Onshore wind and solar will experience the fastest growth in installed capacity, accounting for over 50% of total installed capacity by 2050. Coal installed capacity will peak around 2025 to 2030. Total electricity demand will continue to grow and reach 12,400 TWh in 2050. In terms of primary energy consumption, non-fossil share will rise from 26% in 2030 to 45% in 2050. By end-use, final energy demand growth is driven primarily by the building sector prior to 2030, and then by the transport sector after 2030. In 2030, industry, building and transport sectors account for 40%, 30%, and 30% of total final energy demand, respectively. In terms of CO_2 emissions, China's energy-related CO_2 is projected to peak around 2025 at 10.7 billion tons of CO_2, and decline to 6.8 billion tons CO_2 by 2050. The 2050 CO_2 emissions level is similar to the 2005 level, but with 10-fold growth in national GDP. In other words, CO_2 intensity per unit of GDP reduces by over 50% in 2020, over 70% in 2030, and 90% by 2050, compared to the 2005 level.

China National Renewable Energy Centre (CNREC): China Renewable Energy Outlook (CREO) 2018

The China National Renewable Energy Centre, under China's national government energy think-tank the Energy Research Institute, publishes an annual *China Renewable Energy Outlook* (CREO) that focuses primarily on renewable development but also includes its outlook of national energy demand. The CREO includes a Stated Policy Scenario based on China's current policies and targets, including meeting of its NDCs under the Paris Agreement. It also contains a Below 2 Degree C Scenario that is based on carbon constraints for the energy systems simulated from the IPCC's Fifth Assessment Report database.

In its CREO 2018, CNREC projects that China's primary energy demand will peak around 2025 and begin to decline after. China's final energy demand will peak three years later in 2028 at 3385 Mtce, and decline to 2907 Mtce by 2050. During the 2017 to 2050 period, end-use electricity demand will nearly double and reach 11,355 TWh by 2050, and account for 51% of total final energy consumption. Other fuel sources for meeting final energy consumption in 2050 include 6% from coal, 17% from oil, 9% from natural gas, 12% from district heating, 3% from hydrogen, and 5% from direct renewable use. In the power sector, non-fossil share of generation triples from 2015 to 2050, reaching 86% in the Stated Policies Scenario while coal share declines to 11%. At the same time, wind generation rises from 328 TWh in 2016 to 1,801 TWh in 2030 and 5,955 TWh in 2050, accounting for a 53% share. Solar generation increases to 1,858 TWh in 2035 and 2,694 TWh by 2050, accounting for a 24% share. The rapid rise in renewable generation is supported by significantly growing energy storage capacity, with 1.3 GW in 2020 increasing to nearly 468 GW by 2050. Final energy demand by sector will shift from current shares of 60% in industry, 16% in transport, and 21% in buildings to 42% in industry, 24% in transport and 28% in buildings by 2050. In 2050, industrial final energy demand will only be two-thirds of the 2016 level, with a total of 1,226 Mtce. In contrast, building final energy demand will grow through 2030, when it peaks at 849 Mtce, a level that is 26% above current levels, and decline slightly through 2050. Under the Stated Policies Scenario, CO_2 emissions peak at slightly higher than 10 $GtCO_2$ around 2020 and decline rapidly to 4 $GtCO_2$ in 2050.

China Energy Research Institute (ERI): Integrated Policy Assessment Model of China 2018 Results

China's national government think-tank, the Energy Research Institute, has linked Integrated Policy Assessment Model of China (IPAC) models that it uses to analyze global, national, and regional energy and environmental policies. Although the IPAC model is not used to publish annual outlooks, its modeling results are published periodically in scholarly reports and journal papers. In a 2018 paper, the IPAC model was used to analyze five key scenarios, including the baseline, Low Carbon, Enhanced Low Carbon, 2°C, and 1.5°C scenarios. The Low Carbon scenario considers national policies and strategies as well as resulting enhanced technology improvement, economic development changes, and shifts in consumer behavior. Under its Low Carbon scenario, CO_2 emissions are expected to peak around 2030 and then plateau at around 11 $GtCO^2$ through 2050. Primary energy demand results were not available for the Low Carbon scenario in this 2018 paper.

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Wu, R., Liu, F., Tong, D., Zheng, Y., Lei, Y., Hong, C., Li, M., Liu, J., Zeng, B., Bo, Y., Chen, X., Li, X., Zhang, Q., 2019. "Air quality and health benefits of China's emission control policies on coal-fired power plants during 2005–2020" *Environmental Research Letters* 14 094016, https://doi.org/10.1088/1748-9326/ab3bae

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Appendix 1: Recent China Energy Group Publications

These publications can be downloaded at the links provided below or at: https://china.lbl.gov/publications.

Modeling and Projections

de la Rue du Can, S., Price, L., Zhou, N., and Phadke, A. **"China and India: Energy Service and Related Material Demand Projections"** *38th International Energy Workshop*. Paris, France, 2019. http://eta-publications.lbl.gov/sites/default/files/conference_paper.china_and_india_dream_material_production_projections.pdf

Abstract. The main research question being addressed in this paper is what are the key drivers of energy service and related material demand in China and India given their different stages of economic development? The paper focuses on capturing the main physical drivers of material demand and related energy growth in order to identify what subsectors need to be addressed on a priority basis to develop sustainable pathways to support the forecasted economic growth in both countries. This paper presents detailed assumptions on manufacturing activity and energy intensity to project energy consumption for material production as well as information on fuels and fuel-switching to project energy-related CO_2 emissions. The study describes in detail the methodology and underlying assumptions to develop a bottom-up, transparent baseline scenario to 2050 for both China and India that includes no major new technology breakthroughs and no newly adopted policies. This baseline scenario is developed to form the basis for future development of alternative material production and energy consumption scenarios for policy makers to inform targeted policy interventions.

Lin, J., Fridley, D., Lu, H., Price, L., and Zhou, N., 2018. **"Has coal use peaked in China: Near-term trends in China's coal consumption"** *Energy Policy* 123: 208-214. https://doi.org/10.1016/j.enpol.2018.08.058

Abstract. Coal combustion to power China's factories, generate electricity, and heat buildings has increased continually since Chinese energy use statistics were first published in 1981. From 2013 until 2015, however, this trend reversed and coal use declined from 2810 million metric tons of coal equivalent (Mtce) to 2752 Mtce, leading to a levelling off of China's overall CO_2 emissions. Some analysts have declared that China's coal consumption may have peaked. Preliminary data, however, indicate that coal consumption increased in 2017. To understand future near-term trends in China's coal consumption, we analyze a number of important drivers of coal use and find projected increases in electricity demand that cannot be met by other fossil-fuel or non-fossil-fuel electricity sources, as well as projected increases in coal use in light manufacturing, other non-industrial sectors, and for transformation. We find that these projected increases will lead to near-term growth in China's coal use to levels of approximately 2900 Mtce to 3050 Mtce in 2020, with associated increases in energy-related CO_2 emissions.

Zhou, N., Price, L., Dai, Y., Creyts, J., Khanna, N., Fridley, D., Lu, H., Feng, W., Liu, X., Hasenbeigi, A., Tian, Z., Yang, H., Bai, Q., Zhu, Y., Xiong, H., Zhang, J., Chrisman, K., Agenbroad, J., Ke, Y., McIntosh, R., Mullaney, D., Stranger, C., Wanless, E., Wetzel, D., Yee, C., and Franconi, E. **"A roadmap for China to peak carbon dioxide emissions and achieve a 20% share of non-fossil fuels in primary energy by 2030"** *Applied Energy* 239 (2019) 793 - 819. https://doi.org/10.1016/j.apenergy.2019.01.154

Abstract. As part of its *Paris Agreement* commitment, China pledged to peak carbon dioxide (CO_2) emissions around 2030, striving to peak earlier, and to increase the non-fossil share of primary energy to 20% by 2030. Yet by the end of 2017, China emitted 28% of the world's energy-related CO_2 emissions, 76% of which were from coal use. How China can reinvent its energy economy cost-effectively while still achieving its commitments was the focus of a three-year joint research project completed in September 2016. Overall, this analysis found that if China follows a pathway in which it aggressively adopts all cost-effective energy efficiency and CO_2 emission reduction technologies while also aggressively moving away from fossil fuels to renewable and other non-fossil resources, it is possible to not only meet its *Paris Agreement* Nationally Determined Contribution (NDC) commitments, but also to reduce its 2050 CO_2 emissions to a level that is 42% below the country's 2010 CO_2 emissions. While numerous barriers exist that will need to be addressed through effective policies and programs in order to realize these potential energy use and emissions reductions, there are also significant local environmental (e.g., air quality), national and global environmental (e.g., mitigation of climate change), human health, and other unquantified benefits that will be realized if this pathway is pursued in China.

Khanna, N., Fridley, D., Zhou, N., Karali, N., Zhang, J., and Feng, W. "**Energy and CO_2 implications of decarbonization strategies for China beyond efficiency: Modeling 2050 maximum renewable resources and accelerated electrification impacts"** *Applied Energy* 242 (2019) 12-26. https://doi.org/10.1016/j.apenergy.2019.03.116

Abstract. Energy efficiency has played an important role in helping China achieve its domestic and international energy and climate change mitigation targets, but more significant near-term actions to decarbonize are needed to help China and the world meet the Paris Agreement goals. Accelerating electrification and maximizing supply-side and demand-side renewable adoption are two recent strategies being considered in China, but few bottom-up modeling studies have evaluated the potential near-term impacts of these strategies across multiple sectors. To fill this research gap, we use a bottom-up national end-use model that integrates energy supply and demand systems and conduct scenario analysis to evaluate even lower CO_2 emissions strategies and subsequent pathways for China to go beyond cost-effective efficiency and fuel switching. We find that maximizing non-conventional electric and renewable technologies can help China peak its national CO_2 emissions as early as 2025, with significant additional CO_2 emission reductions on the order of 7 Gt CO_2 annually by 2050. Beyond potential CO_2 reductions from power sector decarbonization, significant potential lies in fossil fuel displaced by renewable heat in industry. These results suggest accelerating the utilization of

non-conventional electric and renewable technologies present additional CO_2 reduction opportunities for China, but new policies and strategies are needed to change technology choices in the demand sectors. Managing the pace of electrification in tandem with the pace of decarbonization of the power sector will also be crucial to achieving CO_2 reductions from the power sector in a scenario of increased electrification.

Jiang, L., Khanna, N., Liu, X., Teng, F., and Wang, X**. "China's Non-CO_2 Greenhouse Gas Emissions: Future Trajectories and Mitigation Options and Potential"** *Scientific Reports* 9, 16095 (2019) doi:10.1038/s41598-019-52653-0

Abstract. Forecasts indicate that China's non-carbon dioxide (CO_2) greenhouse gas (GHG) emissions will increase rapidly from the 2014 baseline of 2 billion metric tons of CO_2 equivalent (CO_{2e}). Previous studies of the potential for mitigating non-CO2 GHG emissions in China have focused on timeframes through only 2030, or only on certain sectors or gases. This study uses a novel bottom-up end-use model to estimate mitigation of China's non-CO_2 GHGs under a Mitigation Scenario whereby today's cost-effective and technologically feasible CO2 and non-CO_2 mitigation measures are deployed through 2050. The study determines that future non-CO_2 GHG emissions are driven largely by industrial and agricultural sources and that China could reduce those emissions by 47% by 2050 while enabling total GHG emissions to peak by 2023. Except for F-gas mitigation, few national or sectoral policies have focused on reducing non-CO_2 GHGs. Policy, market, and other institutional support are needed to realize the cost-effective mitigation potentials identified in this study.

Emissions Trading

Huang, H., Roland-Holst, D., Springer, C., Lin, J., Cai, W., and Wang, C**. "Emissions trading systems and social equity: A CGE assessment for China"** *Applied Energy* 235 (2019) 1254 - 1265. https://doi.org/10.1016/j.apenergy.2018.11.056

Abstract. Carbon dioxide emissions trading systems (ETS) are an important market-based mitigation strategy and have been applied in many regions. This study evaluates the potential for a national ETS in China. Using a dynamic computable general equilibrium (CGE) model with detailed representations of economic activity, emissions, and income distribution, we examine alternative mitigation policies from now until 2050. Based on statistical and survey data, we disaggregate the labor and household sectors and simulate the impacts of ETS policies on the incomes of different household groups. We find that ETS has the potential to reconcile China's goals for sustained, inclusive, and low-carbon economic growth. Results show some key findings. First, the number of unemployed people in energy-intensive industries such as coal and construction will continue to increase; by 2050, employment in the coal industry will decline by 75%. Second, if the scope of the carbon market extends to all industries in China, carbon market revenues will continue to increase, reaching a maximum of 2278 billion yuan ($336 billion) in 2042 to become the world's largest carbon market. Third, the distribution of benefits from the national ETS can help achieve greater social equity. By comparing different distribution policies, we find that the combination of targeted subsidies for unemployed coal

workers and direct household subsidies based on proportional per capita will reduce the social income gap to the greatest extent compared with other scenarios. By 2050, this distribution policy will reduce the Gini coefficient in China by 10% compared to the Business as Usual (BAU) scenario.

Springer, C., Evans, S., Lin, J., and Roland-Holst, D. **"Low carbon growth in China: The role of emissions trading in a transitioning economy"** *Applied Energy* 235 (2019). https://doi.org/10.1016/j.apenergy.2018.11.046

Abstract. China's leaders are increasingly committed to low-carbon economic development. Although China's economy has dramatically transformed since the initiation of economic reforms in 1978, it is still structurally different from post-industrial, high-income countries, and economic reform is ongoing. At the same time, China is taking major steps towards regulating its carbon dioxide emissions. China is currently preparing to implement a national carbon dioxide emissions trading system (ETS), which will be the largest ETS in the world. Our analysis demonstrates how these major economic and emissions policies are linked in China's economy. We use a dynamic computable general equilibrium (CGE) model of China's economy to simulate the interaction between a structural transition policy and a national ETS. We demonstrate an important policy instrument – the household savings rate – for stimulating economic transition. We show that by increasing consumption in lower emissions-intensity sectors, China can sustain growth in its economy while reducing emissions and transitioning to a more OECD-like economic structure. In addition, emissions reductions from an ETS regulation can be achieved at a lower cost for regulated firms when taking into account the changing structure of the economy.

Electricity Market Reform

Abhyankar, N., Lin, J., Liu, X., and Sifuentes, F. "**Economic and environmental benefits of market-based power-system reform in China: A case study of the Southern grid system"** *Resources, Conservation and Recycling* 153 (2020) 10455 https://doi.org/10.1016/j.resconrec.2019.104558

Abstract. China, whose power system accounts for about 13% of global energy-related CO_2 emissions, has begun implementing market-based power-sector reforms. This paper simulates power system dispatch in China's Southern Grid region and examines the economic and environmental impacts of market-based operations. We find that market-based operation can increase efficiency and reduce costs in all Southern Grid provinces—reducing wholesale electricity costs by up to 35% for the entire region relative to the 2016 baseline. About 60% of the potential cost reduction can be realized by creating independent provincial markets within the region, and the rest by creating a regional market without transmission expansion. The wholesale market revenue is adequate to recover generator fixed costs; however, financial restructuring of current payment mechanisms may be necessary. Electricity markets could also reduce the Southern Grid's CO_2 emissions by up to 10% owing to more efficient thermal dispatch and avoided hydro/renewable curtailment. The benefits of regional electricity markets with expanded transmission likely will increase as China's renewable generation increases.

Lin, J., Kahrl, F., Yuan, J., Liu, X., and Zhang, W. **"Challenges and strategies for electricity market transition in China"** *Energy Policy* 133 (2019) 110899. https://doi.org/10.1016/j.enpol.2019.110899

Abstract. China is currently pursuing electricity reforms that will create wholesale markets for electricity. Electricity markets hold considerable promise for facilitating China's transition to clean energy systems, but face obstacles. The most significant obstacle to market reforms is their potential financial impact on coal generation, which currently accounts for most of China's generating capacity. In this paper, we examine the impact of market reforms on coal generation in China, using Guangdong Province as a case study. We find that, in the near term, market prices are likely to lead to significant decreases in net revenues for coal generators relative to the current benchmark tariff, with 40%–60% of coal generation capacity unable to cover the cost of remaining in commercial operation. We estimate that existing coal generators in Guangdong had 94 billion yuan (US$14 billion) in outstanding debt in 2016, creating large risks for banks and raising questions about the potential impacts of electricity market reforms on China's financial industry. The impact of market reforms on coal generators creates two problems—transition and resource adequacy. The development of mechanisms for long-term resource adequacy provides a common solution to both of these problems.

Hu, J., Yan, Q., Li, X., Jiang, Z.Z., Kahrl, F., Lin, J., and Wang, P. **"A cooperative game-based mechanism for allocating ancillary service costs associated with wind power integration in China"** *Utilities Policy* 58 (2019) 120 - 127. https://doi.org/10.1016/j.jup.2019.05.008

Abstract. Wind power in China is developing rapidly. However, wind power curtailment has become increasingly severe, reaching 15% in 2015. The root cause of wind power curtailment in China is that its power system has insufficient flexibility. We analyze how to achieve a reasonable allocation of ancillary service costs for wind power plants, using a cooperative game approach. The analysis shows that, while the current allocation approach in the Beijing, Tianjin, and Tangshan power grid is based only on wind feed-in tariffs, an allocation method based on both the feed-in tariff and the capacity credit of wind would be more reasonable.

Lin, J., Kahrl, F., Yuan, J., Chen, Q., and Liu, X. **"Economic and carbon emission impacts of electricity market transition in China: A case study of Guangdong Province"** *Applied Energy* 238 (2019) 1093 - 1107. https://doi.org/10.1016/j.apenergy.2019.01.128

Abstract. China's electricity system is the world's largest, in terms of installed generating capacity, and is also the world's largest single source of greenhouse gas emissions. In 2015, China embarked on reforms in its electricity sector that aim to introduce market mechanisms in wholesale pricing. This study provides a quantitative assessment of the economic and carbon dioxide (CO_2) emission impacts of transitioning to electricity markets in China, focusing on Guangdong Province. We find that market reforms deliver significant annual cost savings (21 to 63 billion yuan, 9%–27% reduction in total costs in a base case) to consumers in Guangdong, with smaller production cost savings (12 billion yuan, 13% reduction in production costs in a base case). Savings for consumers are accompanied by a large reduction in net revenues for coal and natural gas generators, raising concerns about generator solvency, longer-term resource adequacy, and the need for transition mechanisms. Market reforms increase CO_2 emissions in Guangdong, as a result of gas-to-coal switching, though higher hydropower imports from neighboring provinces could offset these emissions. CO_2 pricing has a limited impact on CO_2 emissions in the short run and has the potential to lead to significant wealth transfers. The most important benefit of market reforms will be in providing an economic framework for longer-term operations and investment.

Buildings Energy Use

Zhou, N., Khanna, N., Feng, W., Ke, J. Levine, M. **"Scenarios of energy efficiency and CO_2 emissions reduction potential in the buildings sector in China to year 2050"** *Nature Energy* (2018). https://doi.org/10.1038/s41560-018-0253-6

Abstract. As China's rapid urbanisation continues and urban dwellers become more affluent, buildings will exhibit a great potential for rapid growth in energy use. To understand how this growth can be slowed, we explore four scenarios for Chinese buildings, ranging from high energy demand (HI) scenario of no new energy policies to lowest energy demand under techno-economic potential (TEP) scenario assuming full deployment of cost-effective efficient and renewable technologies by 2050. We show that even in the highest scenario (HI), building energy demand has an average annual growth rate that is only 60% that of GDP (2.8% vs. 4.6%) with slower growth rates in the other three scenarios. In all scenarios, CO_2 emissions grow slower than energy with building CO_2 peaking around 2045 in HI, and as early as 2030 in TEP. We find that technologies, systems, and practices can be very effective in minimizing building energy use but rigorous policies are needed to overcome multiple implementation barriers.

Hou, T., Cai, W., Ren, H., Feng, W., Zhu, M., Lang, N., and Gao, J**. "China's building stock estimation and energy intensity analysis"** *Journal of Cleaner Production* 207 (2019) 801 - 813. https://doi.org/10.1016/j.jclepro.2018.10.060

Reliable and objective data regarding building stock are essential for predicting and analyzing energy demand and carbon dioxide emissions. However, China's building stock data are lacking. This study proposes a set of China building floor space estimation methods (CBFSM) based on the improved building stock turnover model. It then measures China's building stocks by vintage and type from 2000 to 2015, as well as building energy intensity (national level and provincial level) and energy-efficient buildings. Results show that total building stocks increased significantly, rising from 35.2 billion m^2 in 2000 to 63.6 billion m^2 in 2015, with an average annual growth rate of 4.0%. The deviations were well below 10% by comparing with the *China Population Census*, which validated the reliability of CBFSM and the results. As for energy intensity, both urban dwellings and rural dwellings showed relatively a stable and increasing trend. The commercial building energy intensity saw a downward trend during the "12th Five Year Plan" period, indicating the effectiveness of building energy efficiency work for commercial buildings since 2005. Even so, 38.6 billion m^2 residential dwellings and 5.7 billion m^2 commercial buildings still need to be retrofitted in the future. The CBFSM can overcome shortages in previous studies and it can also provide the Chinese government with technical support and data evidence to promote buildings energy efficiency work.

Appliances and Equipment Energy Use

Karali, N., Shah, N., Park, W.Y., Khanna, N., Ding, C., Lin, J., Zhou, N. **"Improving the energy efficiency of room air conditioners in China: costs and benefits"** *Applied Energy* 258 (2020). https://doi.org/10.1016/j.apenergy.2019.114023

Abstract. China is the world's largest consumer of room air conditioners, and it contributes about a quarter of global space cooling CO_2 emissions. We model the costs and benefits of recently proposed new room air conditioner minimum energy performance standards (MEPS) in China. Our results suggest that newly proposed MEPS brings accumulative CO_2 emissions reductions of 12.8% between 2019 and 2050, and accumulative bill saving of 2,620 billion RMB to China's consumers. The benefits of the proposed MEPS decrease with longer MEPS revision intervals and increase with shorter intervals—indicating that the intervals should be balanced to maximize benefits while accommodating constraints due to air conditioner manufacturer design cycles. We also model potential nationwide benefits from higher MEPS. Across two increasingly aggressive MEPS scenarios, China's room air conditioner electricity consumption and CO_2 emissions in 2050 are both reduced by 15%–53% compared to the proposed MEPS. The highest-efficiency scenario (reaching MEPS of annual performance factor 5.4 in 2025) provides the largest long-term national benefits. These results could inform development of a Chinese regulatory regime that effectively updates room air conditioner MEPS. Because China is the world's largest manufacturer of room air conditioners, the economic, energy, and emissions benefits resulting from higher Chinese MEPS could also have a global reach.

Khanna, N., Ding, C., Won, Y.P., Shah, N., and Lin, J. **Market Assessment of Multi-split Air Conditioning Systems in the Chinese and Global Market**. Berkeley, CA: Lawrence Berkeley National Laboratory. 2019.

Abstract. Commercial air conditioning systems present a key opportunity for reducing greenhouse gas emissions by reducing fossil fuel-based electricity consumption through improved efficiency and through transitioning to refrigerants with low greenhouse gas warming potential (GWP). In particular, variable refrigerant flow (VRF) is a rapidly growing category of multi-split air conditioning (AC) systems that now accounts for a quarter and more than half of the global and Chinese markets, respectively. This report reviews the multi-split AC market in China and its key demand growth drivers, followed by a detailed market assessment of the Chinese multi-split market by size and capacity, by efficiency levels, and by manufacturers. A summary of the global market and recent technology trends and refrigerant choices is also provided to inform revision of the 2008 China minimum energy performance standards (MEPS) for multi-connected AC equipment and revision of MEPS for multi-connected AC equipment globally.

Industrial Sector Energy Use

Liu, X., Lin, J., Hu, J., Lu, H., and Cai, J. **"Economic Transition, Technology Change, and Energy Consumption in China: A Provincial-Level Analysis"** *Energies* 12.13 (2019) 2581. https://www.mdpi.com/1996-1073/12/13/2581

Abstract. This paper conducts panel analysis to evaluate the effects of a structural economic shift from the industrial to the tertiary sector, a reduction in industrial overcapacity, and improvements in energy efficiency on energy consumption using data for 30 Chinese provinces from 1995 to 2015. We find that, at the national level, the structural shift to the tertiary sector, the reduction in cement and steel production, and the increase in energy efficiency in the industrial sector all have statistically significantly negative effects. We also divide the sample into three geographic and economic regions to evaluate regional differences. We find that the gross domestic product (GDP) share of the tertiary sector shows its greatest impact on reducing energy consumption in the eastern region, a decline in heavy industry production would reduce energy demand more in the central region, and improvement in industrial electricity efficiency would also help reduce energy consumption the most in eastern China. We also forecast energy consumption in China will reach 4.8–4.9 billion tonnes of coal equivalent (tce) in 2020 and further grow to 5.0–5.4 billion tce in 2030.

Liu, X., Shen, B., Price, L., Hasanbeigi, A., Lu, H., Yu, C., and Fu, G. **"A review of international practices for energy efficiency and carbon emissions reduction and lessons learned for China."** *WIRES Energy and Environment* (2019). https://doi.org/10.1002/wene.342

Abstract. China's industrial sector dominates the country's total energy consumption, and improving energy efficiency in that sector is crucial to help China reach its energy and carbon dioxide emissions reduction goals. There are many energy efficiency policies in China, but the motivation and willingness of enterprises to improve energy efficiency has weakened. This article first identifies barriers that enterprises face to be self-motivated to implement energy efficiency measures and then categorizes these barriers into four categories: awareness, information, technical capacity, and financial availability. It then reviews international policies and programs to improve energy efficiency, and evaluates how these policies have helped to address the barriers identified. We found that policies and programs in energy efficiency and carbon reduction need to go hand in hand to incentivize companies, and that those policies and programs send clearer signals and help change enterprises' decisions when they are persistent but dynamic. Our specific policy recommendations to China fall under three key categories: identification of energy efficiency potential, workforce development, and market channels for energy efficiency financing.

Energy Production Issues

Zhou, N., Zhang, J., Khanna, N., Fridley, D., Jiang, S., and Liu, X. **"Intertwined Impacts of Water, Energy Development, and Carbon Emissions in China"** *Applied Energy* 238 (2019) 78 - 91. https://doi.org/10.1016/j.apenergy.2018.12.085

Abstract. China is rapidly expanding its alternative and non-conventional energy production capabilities. Although renewable electricity remains the focus, considerable investment has supported construction of coal liquefaction and coal gasification facilities in the desert steppes of north-central China, new coal mines in arid Inner Mongolia, and tight oil and gas extraction in the Ordos to supplement limited domestic supplies of oil and gas. At the same time, China is also facing severe drought and water scarcity in these same regions and in response has expanded various water supply technologies such as desalination and wastewater treatment. Recent government goals and measures for reducing energy and water consumption and increasing efficiency introduced in national policies, however, are poorly or not coordinated, resulting in contradictory objectives for which physical interlinkages are not well understood. This research intends to provide insights for future energy-water nexus management decisions in China, through systematic, comprehensive modeling of the water-energy nexus in China based on comprehensive, bottom-up technology characterizations. Existing studies fail to adequately characterize the details on specific technologies, nor do they comprehensively cover all energy sectors, including energy conversion for non-energy products. We developed integrated assessment (IA) capabilities to allow stakeholders to observe the tradeoffs between various technology options and policy decisions and to test hypotheses/premises in a scenario-driven environment. The results of our analysis underscore the growing interconnection between water and energy in China, the mixed trade-offs from developing low-carbon technologies such as renewable energy and inland nuclear, and the importance of water-energy nexus issues at the regional and local scales. This study lays the groundwork for an integrated resource policy planning process in China and provides an assessment methodology and

research directions for future studies of the water-energy nexus. Finally, this study contributes to the water-energy nexus literature by providing systematic data and policy implications for China, where data are typically less accessible, as well as providing references for other regions in the world that are facing similar water and energy use and planning challenges.

Lu, X., Cao, L., Wang, H., Peng, W., Xing, J., Wang, S., Cai, S., Shen, B., Yang, Q., Nielsen, C.P., and McElroy, M.B., 2019. **Gasification of coal and biomass as a net carbon negative power source for environment-friendly electricity generation in China** *Proceedings of the National Academy of Sciences of the United States of America.* www.pnas.org/cgi/doi/10.1073/pnas.1812239116

Abstract. Realizing the goal of the Paris Agreement to limit global warming to 2°C by the end of this century will most likely require deployment of carbon-negative technologies. It is particularly important that China, as the world's top carbon emitter, avoids being locked into carbon-intensive, coal-fired power-generation technologies and undertakes a smooth transition from high- to negative-carbon electricity production. We focus here on deploying a combination of coal and biomass energy to produce electricity in China using an integrated gasification cycle system combined with carbon capture and storage (CBECCS). Such a system will also reduce air pollutant emissions, thus contributing to China's near-term goal of improving air quality. We evaluate the bus-bar electricity-generation prices for CBECCS with mixing ratios of crop residues varying from 0 to 100%, as well as associated costs for carbon mitigation and co-benefits for air quality. We find that CBECCS systems employing a crop residue ratio of 35% could produce electricity with net-zero life-cycle emissions of greenhouse gases, with a levelized cost of electricity of no more than 9.2 US cents per kilowatt hour. A carbon price of approximately $52.0 per ton would make CBECCS cost-competitive with pulverized coal power plants. Therefore, our results provide critical insights for designing a CBECCS strategy in China to harness near-term air-quality co-benefits while laying the foundation for achieving negative carbon emissions in the long run.

Appendix 2: Scenario Comparison Summary

Summary of International and Chinese Modeling Study Scenarios' Key Results Comparisons

Outlook	Key Energy Findings	Key Electricity or Non-Fossil Findings	Key CO_2 Emissions Findings
Berkeley Lab's *China Energy Outlook*	China will meet its 2020 and 2030 goals to cap primary energy consumption by 5000 Mtce and 6000 Mtce, respectively. China will fall short of meeting its 2030 goal of >15% natural gas (<10%).	China will meet its 2020 goal of 15% non-fossil energy, and nearly meet its 2030 goal of >20% non-fossil energy (19.7%). China will nearly meet its 2030 goal of >50% renewable generation (45%).	China will meet its goal to peak CO_2 emissions by 2030 or earlier.
China Petroleum & Chemical Corporation (Sinopec), 2019. *China Energy and Petrochemical Industry Development Report*.	Total primary energy peaks around 2045 with 6 Btce. Coal = 34% of total primary energy by 2050. Oil peaks ~ 2030 with 720 million tons. Natural gas peaks around 2050 with 700 billion m^3 (650 Mtoe, 929 Mtce).	In 2050, China's non-fossil energy installed capacity will be over 2800 GW, generating 7300 TWh of electricity. Non-fossil reaches 1.4 btoe (2 Mtce) by 2050 accounting for 35% of total primary energy.	China will reach CO_2 emissions peak before 2030 at around 9.9 billion tons.
State Grid Energy Research Institute. *China Energy and Electricity Outlook 2018*.	China primary energy consumption peaks at 5.8 Btce in 2040.	By 2025, electricity will replace coal as the top energy for final energy demand. Non-fossil share of electricity reaches 60% in 2035 and 78% in 2050. Non-fossil share of primary energy use reaches 37% in 2040 and 45% in 2050.	Energy-related CO_2 emissions peak around 2025 at about 10.7 $GtCO_2$. Under the normal transition scenario, CO_2 emissions reduce to 6.8 $GtCO_2$ in 2050.

China National Petroleum Corporation Research Institute of Economics and Technology. *World and China Energy Outlook to 2050*, 2018 version.	China primary energy consumption peaks/plateaus around 2035-2040 at about 5.6 Btce.		Energy related CO_2 emissions peak before 2030.
China National Renewable Energy Center. 2018. *China Renewable Energy Outlook*.	Primary energy consumption peaks in 2025.		CO_2 emissions peak at slightly higher than 10 $GtCO_2$ around 2020, and reach 4 $GtCO_2$ in 2050
2019 IEA *World Energy Outlook* – Stated Policies Scenario	China primary energy consumption continues to grow but at a slower pace to 2040, reaching 5680 Mtce in 2040.	Electricity replaces coal and oil as the main source of energy by 2040, representing 35% of total energy consumption.	Energy related CO_2 emissions peak at 2025 at 10.0 $GtCO_2$.
2019 BP *Energy Outlook* (China section)	Energy demand growth will decline to an average of 1.1% per year, resulting in an average 3.4% annual decline in economic energy intensity. In absolute terms, energy demand will increase from 4,490 Mtce to 5,744 Mtce.		China's CO_2 emissions peak by 2022.
2019 ExxonMobil *Outlook*	China's primary energy consumption will grow to 5.1 Btce in 2030 and 5.3 btce in 2040.		China energy-related CO_2 emissions peak around 2025 at 9.6 $GtCO_2$, and decline to 8.5 Gt in 2040.
Bloomberg New Energy Finance *New Energy Outlook 2019*	Peak coal generation is in 2027.	China's electricity system reached 37% renewable penetration by 2027. By 2050, China has 1.3 TW of Solar PV and 1.2 TW of wind installed capacity. Nuclear grows to 182 GW by 2050. China's wind and solar grow from 8% to 48% of total generation by 2050.	Coal generation related CO_2 emissions peaks by 2027.

China Energy Research Institute (ERI) IPAC Model – Low Carbon Scenario	Not available.		China's CO_2 emissions peaks around 2030 at 11 $GtCO_2$, and then plateau through 2050.

Appendix 3: China Energy Outlook Continuous Improvement Scenario Assumptions for End-Use Sectors

Industrial Sector Activity and Technology Assumptions

	2010	Continuous Improvement Scenario 2050
Sectoral Activity Demand		
Total industry value added	11 RMB trillion (2005)	66 RMB trillion (2005)
Share of low-value-added, energy-intensive industry (value-added basis)	30%	20%
Steel Production (million tons)	637	619
Cement Production (million tons)	1882	1496
Energy Efficiency Improvement		
Energy intensity (EI) values for sub-sectors modeled on physical basis	EI based on government statistical data	EI improves to meet or slightly exceeds 2015 advanced economies' levels
Steel sector averaged final EI (tce/t)	0.67	0.33
Cement sector averaged final EI (tce/t)	0.128	0.081
EI values for sub-sectors modeled on value-added basis	EI based on government statistical data	EI improves to meet or slightly exceeds 2015 advanced economies' levels
Fuel Switching		
Sectoral Fuel Mix*	Coal (including coke): 60% Gas: 3% Electricity: 19% Petroleum: 10% Other (including heat): 8%	Coal (including coke): 29% Gas: 11% Electricity: 41% Petroleum: 11% Other (including heat): 9%

Building Sector Activity and Technology Assumptions

	2010	Continuous Improvement Scenario 2050
Building Activity Demand		
Total residential floor area	40.8 billion square meters	62.9 billion square meters
Urban residential: proportion of pre-2010 existing building stock that is retrofitted	2% of existing stock of buildings built before 2010	75% of existing stock of buildings built before 2010
Urban residential: proportion total floorspace that is new, post-2010 constructed	0%	2020: 43% 2030: 64% 2040: 79% 2050: 89%
Total commercial floor area	11.9 billion square meters	23.4 billion square meters
Commercial retrofit: proportion of retrofitted pre-2010 existing building stock	0.4% of stock	75% of existing stock of buildings built before 2010
Commercial: proportion of new, post-2010 constructed buildings of total floorspace	0%	2020: 46% 2030: 63% 2040: 77% 2050: 87%
Building vintage shares of pre-2010 existing buildings stock	98% no retrofits, 2% current best practice retrofits	Non-linear decline of no retrofits to 65% in 2020, 45% in 2030, 33% in 2040, and 25% in 2050. In North China, increase of best possible retrofits to 7% in 2020, 16% in 2030, and 50% in 2050. In Transition zone, increase of best possible retrofits to 5% in 2020, 12% in 2030 and 30% in 2050. In South China, increase of best possible retrofits to 2.5% in 2020, 6% in 2030 and 15% in 2050. Current best practice retrofits is the remaining share.
Building vintage shares of post-2010 new buildings stock	100% current best practice new buildings, 0% ultra-low energy buildings	Increase of ultra-low energy buildings to 50% by 2050 in North China, 20% by 2050 in Transition zone, and 10% by 2050 in South China. Current best practice new buildings is the remaining share.
Building load changes: space heating		Heating loads increase from 2010 to 2050 in North, Transition and South (urban only) China due to demand for greater thermal comfort. Specific loads differ by building vintage types.
Building load changes: cooling		Cooling loads increase significantly from 2010 to 2050 in all climate zones (particularly Transition and South) due to demand for greater thermal comfort

Residential Building Efficiency Improvements		
Appliance and equipment efficiency improvements	100% adoption of current existing technology in 2010	Linear shift to 100% adoption of current superefficient technology by 2050
Residential Building Fuel Switching		
Fuel switching: heating		Urban: faster penetration of air source heat pump to 10% by 2050 with lower gas district heating shares. Rural: a phase out of all coal stoves by 2050, replaced by growing shares of biomass, solar thermal, air source heat pump and some coal boilers.
Fuel switching: cooking		Urban: complete phase out of all coal-based cooking and faster decline of liquified petroleum gas (LPG) cookers, replaced with greater shares of electric cookers and natural gas cookers. Rural: complete phase-out of coal stoves and declining shares of LPG cookers, replaced by electric cookers and biomass.
Fuel switching: urban water heating		Faster decline in electric heaters and replaced by faster growth in solar water heaters to 50% by 2050. Natural gas water heaters decline slightly.
Commercial Buildings Energy Demand and Efficiency Improvements		
Building load changes: space heating		Lower (but still rising) heating loads for best possible retrofits and ultra-low energy buildings due to superior design and thermal insulation
Building load changes: cooling		Lower (but still rising) cooling loads for best possible retrofits and ultra-low energy buildings in all climate zones
Equipment efficiency improvements	100% adoption of current existing technology	100% adoption of current superefficient technology by 2050
Heating Efficiency:	North: 63% Transition: 66% South: N/A	North: 81% Transition: 117% South: N/A
Cooling Efficiency:	North: 100% Transition: 100% South: 100%	North: 258% Transition: 258% South: 258%
Commercial Building Fuel Switching*		
Fuel switching: cooling		Geothermal heat pumps phase out by 2050, replaced by more centralized air conditioning
Fuel switching: water heating		Complete phase out of coal and oil boilers and rapid decline of gas boilers shares, replaced by 45% solar water heaters, 10% air source heat pumps, and 14% small cogeneration by 2050.

Transport Sector Activity and Technology Assumptions

	2010	Continuous Improvement Scenario 2050
Transport Activity Assumptions		
Urban Bus (billion veh-km)	21.8	63.9
Urban Rail (billion veh-km)	5.57	98.8
Urbal Light-duty Passenger (cars, taxis, fleet cars) (billion veh-km)	797.4	5983.4
Urban Motorcycle (billion veh-km)	257.6	796.7
Passenger Water (billion pass-km)	7.2	14.1
Passenger Air (billion pass-km)	403.9	2308.3
Freight Road (billion veh-km)	651.4	1383.4
Freight Rail (billion ton-km)	2764.4	11073.4
Freight Air (billion ton-km)	17.9	175.2
Freight Water (billion ton-km)	2244.4	10369.8
Transport Efficiency Assumptions*		
Private Car Fleet Averaged Final Energy Fuel Intensity (MJ/veh-km)	2.7	1.0
Urban Bus Fleet Averaged Fuel Intensity (MJ/veh-km)	9.4	5.8
Intercity Truck Fleet Averaged Fuel Intensity (MJ/veh-km)	7.6	4.4
Freight Rail Averaged Fuel Intensity (MJ/ton-km)	0.074	0.035
Transport Fuel Switching Assumptions**		
Private Car Fleet shares by technology/fuel type:		
Gasoline	99.9%	59%
Diesel	0.04%	3%
Natural Gas	0.1%	0%
LPG	0.05%	0%
Plug-in Hybrid EV	0%	0%
EV	0%	38%
Urban Light-duty Bus Fleet shares by technology/fuel type:		
Gasoline	22.5%	0%
Diesel	77.5%	63%
CNG		

EV	0%	15%
Plug-in Hybrid EV	0%	22%
	0%	0%
Urban Light-duty Truck Fleet shares by technology/fuel type:		
Gasoline	40.9%	8%
Diesel	58.9%	12%
CNG	0.2%	30%
Diesel Plug-in Hybrid	0%	50%

*Note: The average intensity values provided here are averaged across the entire fleet, taking into consideration the mix of different vehicle sizes (e.g., heavy-duty, medium-duty, light-duty) and fuel technologies.