中国石油消费总量控制和政策研究项目
China Oil Consumption Cap Plan and Policy Research Project

China Oil Consumption Cap Plan and Policy Research Project
Main Report (2019)

RESEARCH ON CHINA'S OIL CONSUMPTION PEAK AND CAP PLAN

CHINA OIL CAP PROJECT

In order to address climate change and reduce environmental pollution, China Oil Consumption Cap Plan and Policy Research Project (aka "China Oil Cap Project") was launched in January 2018, with Natural Resources Defense Council (NRDC) and Energy Foundation China (EF China) as the coordinating organization. The project combines resources from over 10 key stakeholders - including government think tanks, academic institutions, and industry associations - to help China peak and reduce its oil consumption and to support China's oil industry to be safer, greener, and more efficient. The project aims to ultimately help China leap over the Oil Age into a clean energy future, helping to conserve resources and protect public health, the environment and the climate.

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- *Research on Biofuel as an Oil Replacement Option in China*
- *The Carbon Reduction Pathways for the City of Hangzhou Under an Oil Cap Scenario*
- *A Study on the True Cost of Oil in China*
- *A Study on the External Cost of Water Resource During Oil Utilization*
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EXECUTIVE SUMMARY

Reasonably capping oil consumption and achieving oil peak as early as possible is of the utmost importance for China to safeguard its energy supply and economic security, tackle climate change, win “the Battle for Blue Skies”, and build a green, low-carbon, and high-quality modern economy. Having consumed 628 million tons of oil in 2018, China is the world’s second largest oil consumer and first largest oil importer, with its oil use and imports continuously expanding over the years. The long-term goal of capping oil consumption in China is that carbon neutrality is achieved by the second half of this century with the joint efforts by China and the international community.

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"Leaping over the age of oil" is the clear path forward for China. After a long period of high oil consumption, major developed countries have accelerated their energy transformation, providing the impetus for China to establish and implement a strategy for "leaping over the age of oil." Currently, major developed countries still rely on oil as a dominant energy source, but their total and per capita oil use have already peaked and since declined significantly, while major international oil companies are also shifting towards clean and renewable energy. Chinese per capita oil use is relatively lower than that of the developed countries; still, under the constraints imposed by limited resources, the environment and climate, China needs to explore an innovative path that is significantly less dependent on oil, thus supporting its goal of building a modern society, and achieving a leapfrog approach to development.

The total external environmental cost of China's oil exploitation and utilization was 507 RMB per metric ton of oil in 2015. Every aspect of oil exploitation and utilization in China—from extraction to transportation, storage, conversion, utilization and product manufacturing—can produce negative or harmful effects on the environment, such as air pollution, water resource damage, soil pollution, health risks and greenhouse gas emissions. The goal of the study on the environmental costs of oil is to help facilitate the gradual internalization of such external costs and provide a basis for the assessment of relevant environmental taxes and fees and for the development of relevant standards, regulations and measures. It will also help boost energy efficiency, foster technology innovation, reduce the emission of pollutants and protect people's health.

Under the oil cap pathway, China's oil consumption can peak by 2025 and basically meet the 'carbon neutral' requirements of the 1.5°C temperature control target by 2050. The oil cap pathway is proposed based on international comparative studies and scenario analysis, taking into account an energy revolution and China's green, low-carbon and quality-oriented economic transition. Under this pathway, China's oil consumption is expected to peak at 720 million tons by 2025; the vision of a "Beautiful China" would be achived by 2035 when the oil consumption would decrease to about 600 million metric tons; the oil consumption would further decline to 420 million tons by 2050. With contributions from the commercialization of Carbon Capture, Utilization and Storage

(CCUS) technology and the expansion of forest carbon-sinks, carbon emissions will be dramatically reduced then.

The five major approaches for capping oil use include reducing demand; improving efficiency; replacing oil with alternative energy sources; optimizing industry structures and product portfolios; and encouraging clean use. By 2050, the oil cap pathway would reduce oil consumption by 350 million metric tons compared to the baseline scenario. Of these reductions, oil replacement accounts for 48%, efficiency improvements account for 20%, structural optimization for 16%, reducing demand accounts for 15%, and clean utilization accounts for 1%. Replacement and efficiency improvements are by far the most significant contributors, accounting for 68% of oil reduction potential.

Oil reduction potential can also be broken down by sectors, of which the transportation sector would account for 66.3%, the petrochemical sector would account for 14.3%, and other sectors would account for 19.4%. The oil consumption structure will experience significant changes. In 2017 the transportation sector was responsible for 57.7% of oil consumption, the petrochemical sector 15.3%, and other sectors 27.0%. However, by 2050 the transportation sector will account for 33.3% of oil consumption, the petrochemical sector 42.4%, and other sectors 24.3%.

The transportation sector is expected to reach oil consumption peak between 2020 and 2023. By 2050, oil consumption in the transportation sector will have decreased by about 232 million tons compared to the baseline scenario. The transportation sector should move in the direction of substitution, increasing efficiency, and clean utilization, making progress from both the supply and demand sides. Fuel substitution approaches, such as vehicle electrification, will contribute 64.7% of the decrease, and efficiency measures such as fuel economy improvements will account for 17.1%. The structural optimization of passenger and cargo transportation and of urban travel, reduction of unreasonable transportation through optimized urban planning, and clean utilization will account for 18.2% of these reductions.

Oil consumption in the petrochemical sector is expected to peak by around 2035, followed by a long plateau. In 2050, petrochemical sector oil consumption will be reduced by about 50 million tons compared to the baseline scenario. Oil reduction measures such as implementing prohibitions and limitations on plastic usage and increasing recycling rates for plastics will contribute around 38% of this reduction. Structural optimization approaches such as controlling the scale of production capacity in the petrochemical sector and reducing indirect oil consumption through optimizing petrochemical export structure will contribute about 30% of this reduction. Increasing overall energy efficiency in the petrochemical sector, implementing supply-side structural reforms, extending the added value of the industrial chain and optimizing the energy consumption structure will contribute about 20%. By increasing imports of petrochemical raw materials or basic products, developing oil-free-based chemical industries and promoting cleaner production, the petrochemical sector will reduce oil consumption and contribute to another 12% of reductions.

Oil consumption in other sectors is expected to peak between 2025 and 2035. Oil is used in various kinds of machinery, including in gasoline and diesel engines, domestic heating, and industrial lubricants. Compared to the baseline scenario, the oil consumption in other sectors will have decreased by 68 million tons in 2050. Of this reduction, improving efficiency standards for gasoline and diesel engines accounts for 29.4%, elimination of backward and highly polluting machinery accounts for 23.5%, replacement with electric and non-oil options, optimization of the engineering operation and production processes, and clean utilization accounts for 47.1%. Oil-consuming machinery in operation cause serious pollution. It is therefore important to improve fuel efficiency and pollution emission standards for gasoline and diesel engines and to implement electric heating substitution.

China's solid, effective and forceful efforts in implementing a cap on oil consumption are supported by three pillars—the ban of traditional fuel-fired vehicles in the transportation sector, the restriction of the usage of some specific plastic products, and the imposition of stricter energy efficiency standards in other sectors. The oil reduction potential of these three pillars in 2050 is 205 million tons, accounting for 58.6% of the 350 million metric tons reduction potential. We recommend that the government formulate and enforce timetables for the areas covered by these three pillars during the 14th Five-Year Plan period (2021-2025) to achive multiple benefits, including reducing carbon emissions, protecting the environment and safeguarding public health.

Specifically for the transportation sector, a detailed and enforceable timetable for the phase-out of traditional fuel vehicles is one of the most influential policy tools available. Many provincial and municipal governments, for example Hainan Provincial Government, have designed and are carrying out a plan for replacing and phasing-out different types of traditional internal combustion engine (ICE) vehicles, laying a solid foundation for the launch of a national scale of the ICE vehicles phase-out policy. Automobile manufacturing companies should formulate timetables for the suspension of the production and sales of traditional ICE vehicles, as well as develop new energy vehicle (NEV) replacement programs according to the evolving policy environment and market demand.

The report points out that traditional ICE vehicles should be phased out according to a timetable that specifies deadlines for different vehicle types, regions and phases. The ban will first be introduced to megacities, large core cities, cities in highly air-polluted regions and pilot NEV cities, where electrification and other types of new energy will be adopted around 2020-2025 for all vehicles used for urban public transportation, sanitation, logistics, commuter service, taxis and ride hailing. The timetable also envisions replacing traditional ICE vehicles with NEVs for all private passenger vehicles by 2040, for commercial vehicles by 2045, and for heavy-duty trucks by 2050. In addition to road traffic, it is also necessary to formulate near, medium, and long-term fuel phase-out plans for water shipping and air operations.

We recommend establishing three indicators for capping oil consumption. The first is a guiding target for the share of oil in total energy consumption. The second is to elevate the mandatory “dual-credit” scheme, which encourages vehicle manufacturers to increase vehicles’ fuel efficiency and produce larger percentage of new energy vehicles, from a sector-level target to a national one. The third is to establish the dependence on foreign oil as an early warning indicator.

During the 14th Five-Year Energy Plan, the share of oil consumption in the primary energy mix should be less than 20%. Energy efficiency and new electric vehicle targets for passenger vehicle should also be tightened every five years. The target for the import oil dependence should be set at 73% or less in 2025, and gradually decline in the future.

The development strategy for “Leaping over the age of oil” with an oil consumption cap at its core will boost economic growth. Market-oriented reforms and institutional innovation will catalyze and nurture new commercial activities. This report recommends that the government speed up the adjustment and removal of unreasonable subsidies for oil consumptionl; build a tax system that reflects the true external cost of oil use; improve fiscal and tax policies that encourage oil saving and substitution; formulate a roadmap for the phase-out of ICE vehicles to promote the automotive technology revolution; reform the investment and management mechanisms of the oil and gas sector to create a market and policy environment that promotes the shale oil and gas revolution; and promote the production of high-value petrochemical products. All these will promote the prosperity of new economy as well as the transformation of traditional industries, driving the economic development.

FOREWORD

The China Oil Consumption Cap Plan and Policy Research Projects (aka "China Oil Cap Project") was officially launched in January 2018, with the National Resources Defense Council (NRDC) and Energy Foundation China (EF China) as coordinators, as well as the involvement of over 10 foreign and domestic influential research institutions.

The China Oil Cap Project attempts to answer one question—Can China leap over the age of oil?

Oil is the world's largest energy source, accounting for about 33% of global energy consumption. In 2018, oil represented 18.9% of China's total energy consumption and the country's oil import dependence was higher than 70%. These figures have been rising year on year, seriously challenging China's oil supply security and environmental protection. This report offers a comprehensive and comparative analysis of China and major developed countries from such perspectives as economic development, energy and oil consumption and policy impact, in order to identify a new path for oil exploitation and consumption in China. With its oil exploitation and use increasingly constrained by factors such as environmental protection, climate change, public health, resource endowment and oil supply security, as well as by high external costs, China is forced to accelerate energy transformation. In this context, achieving oil peak earlier will be the first milestone on China's journey of leaping over the age of oil. Further, an efficient, clean, low-carbon oil consumption model will undoubtedly facilitate China's high-quality social and economic development and help improve people's wellbeing.

However, we are fully aware of the challenges, complexity and long-termness of this journey. This report offers oil cap pathways as well as specific solutions. After 2014, China reached a stage featuring a stable, medium-speed growth in oil consumption, which signals an upcoming turning point. This report concludes that China's oil consumption will peak at approximately 720 million metric tons by 2025. As coal consumption has been steadily declining in China, peaking oil consumption earlier can help the world's 2nd largest economy speed up its pace for peaking carbon emissions. Moreover, China's economic and industrial upgrade, rapid technological progress, continuously improved green finance, intensely competitive market and corporate innovation—All these developments have laid a solid foundation for the country's leaping over the age of oil.

The report does not attempt to accurately "predict" future oil demand, neither does it offer a "panacea" for oil use. What we do is analyze, judge and identify the turning point, trend and direction of future oil consumption; offer some new views, innovative models and effective measures; and recommend policy options to promote and effect these changes. We would be extremely honored if the roadmap of "leaping over the age of oil" and its implementation could help drive China's energy transformation.

It's our belief that China's practices in leaping over the age of oil will provide new perspectives for the world. Today, world energy consumption remains in the age of oil—when people are increasingly concerned about the potential and limits of oil resources, the uniqueness and vulnerability of oil trade, and environmental, climate and other harmful impacts caused by oil exploitation and use. This "leaping over the age of oil" effort is intended to find a solution that will not only enable major oil-consuming countries to break their oil dependence, but will also help developing countries avoid huge oil infrastructure investments and efficiently utilize oil resources to improve the quality of their peoples' lives. Equally important, this endeavor can significantly mitigate the emission of greenhouse gases to protect the environment in which we live.

1

SIGNIFICANCE OF CAPPING OIL CONSUMPTION IN CHINA

Oil is the "blood" of modern social and economic development, a strategic resource that has an important influence on national undertakings and people's livelihood. However, it is also a major source of environmental pollution, ecological degradation and carbon emissions. Today, China is comprehensively advancing its ecological civilization and accelerating its pace to develop a high-quality economy. In this context, peaking oil consumption early and controlling overly rapid growth in oil consumption in China have profound implications for winning "the Battle for Blue Skies", tackling climate change and safeguarding its energy and economic security.

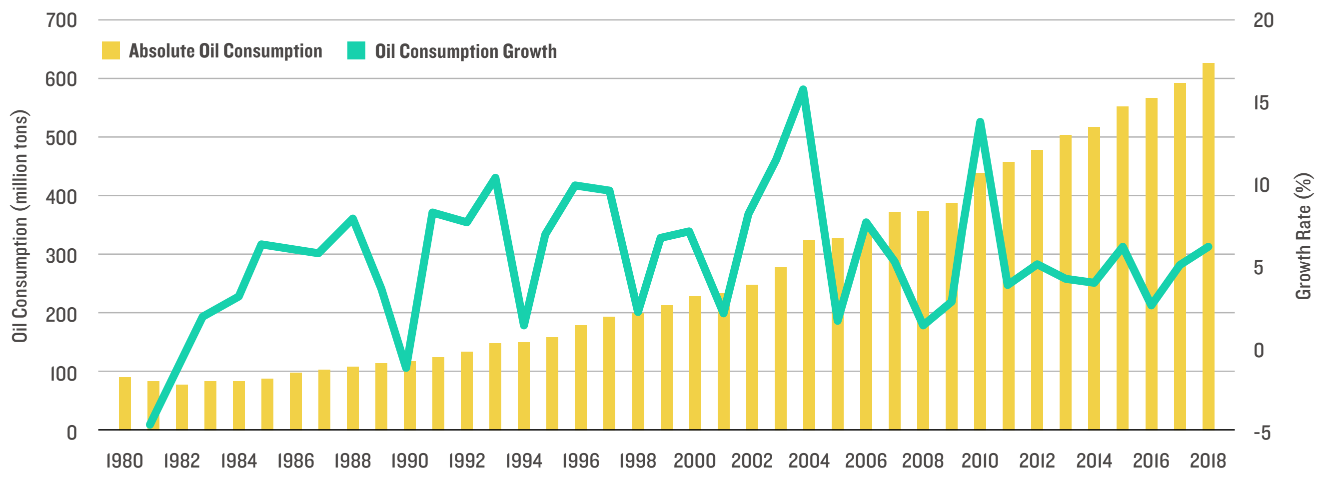
1. CHINA IS A MAJOR OIL CONSUMER AND IMPORTER GLOBALLY

In 2018, China produced 189 million tons of crude oil and imported 462 million metric tons of crude oil, as well as 33.48 million metric tons of refined oil[1]. In total, China consumed 628 million metric tons of oil, which represents 18.9% of China's total primary energy consumption and 13.4% of the world's total oil consumption, ranking second after the US.

During 2014-2018, China experienced an obvious slowdown in primary energy consumption, with an average annual growth rate of less than 2.2%. However, its oil consumption still grew rapidly, at an annual pace of 4.7% during this period. Compared with the ups and downs of oil consumption growth and the higher average annual growth rate of 6.3% during the period from 1990-2013, we can conclude that the growth rate of oil consumption has entered a stable period[2], as shown in Figure 1.1.

Since 1993 when China became a net oil importer, its imports have been increasing rapidly. In 2018, its oil import dependence rose to 70%, making China the world's largest oil importer[3]. In the ten years from 2008 to 2018, total global oil consumption increased by 520 million tons, with 49% of this growth coming from China. By 2030, China is expected to make up about 40% the world's oil consumption growth[4]. China has already become the main driving force for global oil consumption growth and an important player in reshaping the global oil market. At the

FIGURE 1.1: CHINA'S TOTAL OIL CONSUMPTION AND GROWTH RATE (1980-2018)



Source: China Statistical Abstract 2019, edited by the National Bureau of Statistics, China Statistics Press, May 2019

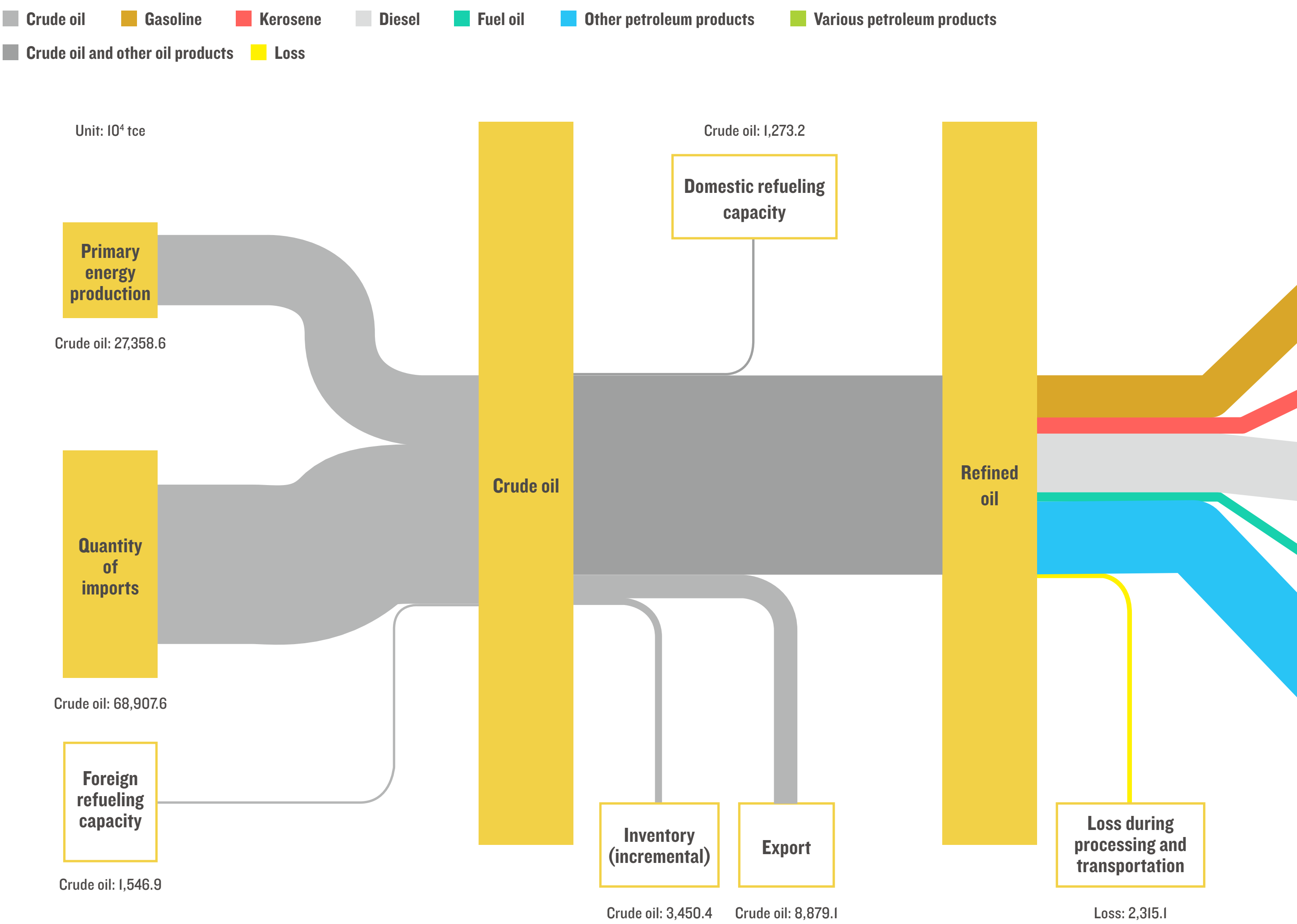
1 Annual Report on National Economic and Social Development in 2018, National Bureau of Statistics, February 28, 2019

2 2019 China Statistical Abstract, National Bureau of Statistics, China Statistics Press, May 2019

3 China Statistical Yearbook 2019, National Bureau of Statistics, China Statistics Press, September 2019

4 BP World Energy Statistical Yearbook 2019, BP, June 2019, 68th edition

FIGURE 1.2: FLOWCHART OF OIL PRODUCTION AND CONSUMPTION IN CHINA (2017)

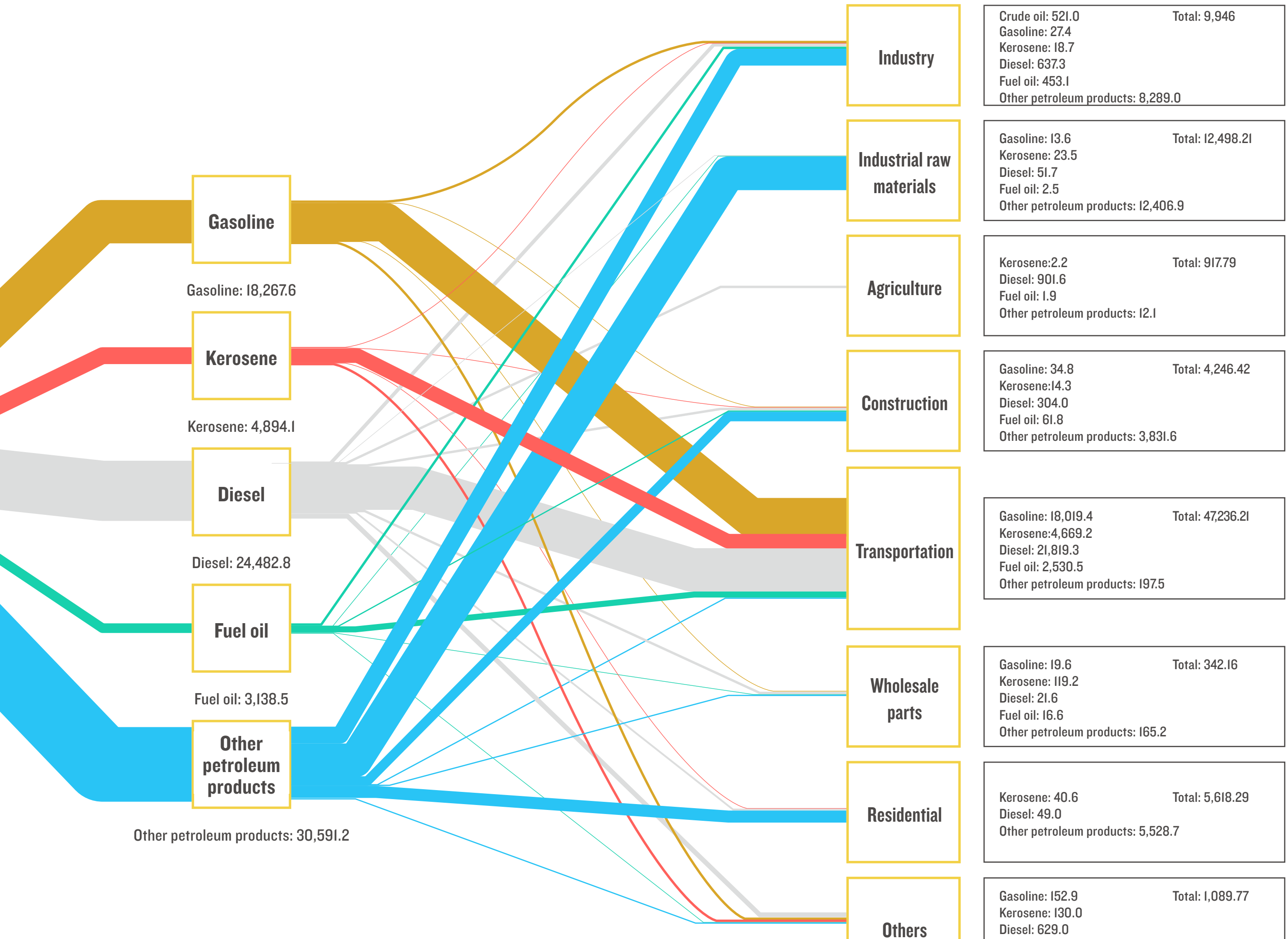


Source: China's 2017 Energy Flow Chart and Oil Flow Chart, Hu Xiulian, Liu Jia, China's Total Oil Consumption Control and Policy Research Project, June 2019

same time, it is facing the challenge of oil supply security.

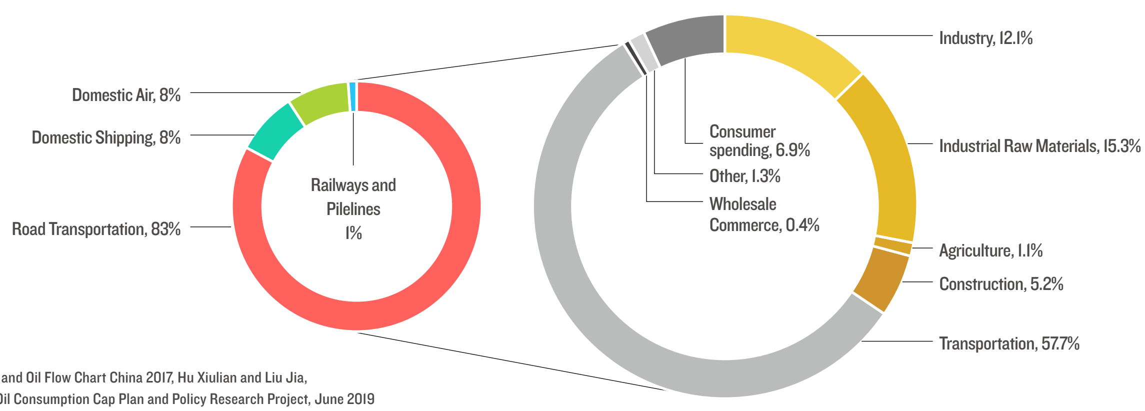
Figure 1.2 shows the flow of oil in different segments of the oil value chain, from exploitation to import and export, transportation, processing, conversion and end use. The oil flow diagram also clearly introduces the amounts of oil used by different sectors in terms of percentages and the efficiency of end use. Through this diagram, we can see oil loss through various segments as well as the potential to reduce this loss. By improving fuel efficiency in various sectors, the overall efficiency of the oil consumption system can be improved.

Oil consumption mainly consists of fuel and raw materials production. The composition by sector of the oil consumption represented in the oil flowchart is shown in Figure 1.3. In 2017, China's oil consumption was 589 million tons, of which the transportation sector accounted for 57.7% and the petrochemical sector (industrial raw materials) for 15.3%. Other industrial sectors, consumer spending, construction, agriculture, wholesale and retail accounted for 12.1%, 6.9%, 5.2%, 1.1%, and 0.4% respectively, and other categories accounted for 1.3%.



Note: Other petroleum products include lubricating oil, paraffin, solvent oil, petroleum coke, refinery dry gas and others.
Because of limited time and resources, the import and export of various oil products are not considered in this flowchart.

FIGURE 1.3: CHINA'S OIL CONSUMPTION RATIO FOR VARIOUS SECTORS (2017)



Source: Energy and Oil Flow Chart China 2017, Hu Xiulian and Liu Jia,
China Oil Consumption Cap Plan and Policy Research Project, June 2019

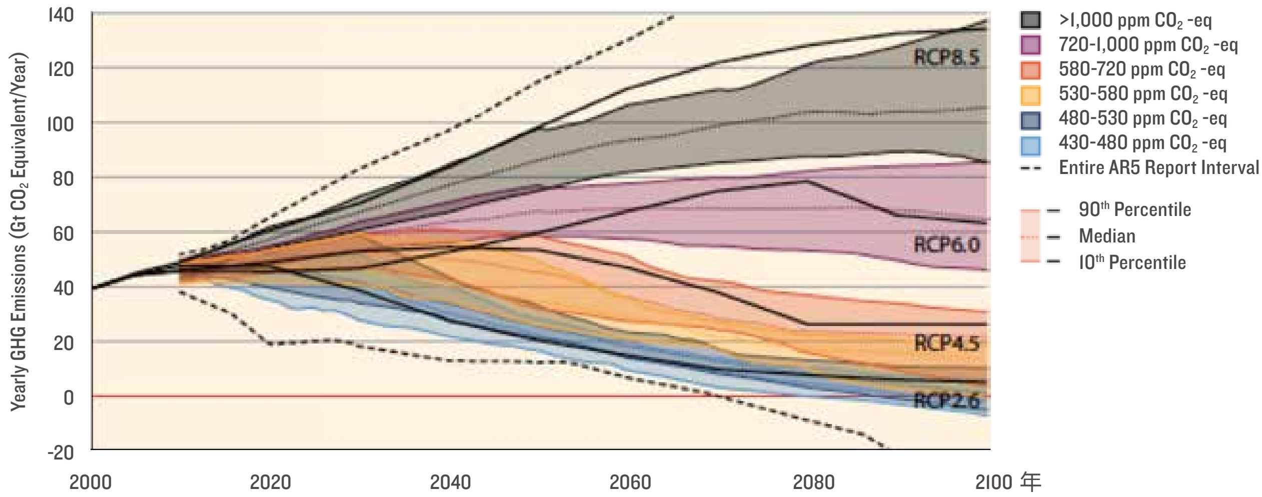
2. CLIMATE CHANGE POSES LONG-TERM CONSTRAINTS ON OIL CONSUMPTION

The Paris Agreement reached in 2015 clearly states its aims of holding the increase in global average temperatures 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. It also seeks to reach a global peak in greenhouse gas emissions as soon as possible and to achieve carbon neutrality by the second half of this century. In October 2018, the Intergovernmental Panel on Climate Change (IPCC) released the *Special Report on Global Warming of 1.5°C (SR15)*, which highlights the likelihood of global warming reaching 1.5°C as soon as in 2030, as well as the need for countries to raise ambitions and goals in their emission reduction targets. According to an IEA study, to achieve the 2°C target, the global greenhouse gas emissions must be reduced by 40%-70% relative to 2017 levels by 2050, see Figure 1.4.

As the world's largest emitter of CO_2, China generated 27% of the world's total carbon emissions in 2017. It is an important participant in, contributor to and pioneer of global efforts to combat climate change. China peaked its coal consumption in 2013, with its carbon emissions from coal use reduced by approximately 650 million metric tons relative to 2013 levels. During the same period, CO_2 emissions from oil consumption increased by about 370 million metric tons, partly offsetting the reduction in carbon emissions from coal[5].

During the five years from 2013 to 2018, the cumulative increase in CO_2 emissions from the energy sector was zero. Unlike previous decades when carbon emissions grew rapidly, this five-year period was the first time China reached a plateau in carbon emissions[6]. If oil, which is China's second largest energy source, can reach an early peak in consumption, we can expect that the goal of peaking CO_2 emissions around 2030 as stated in China's intended Nationally Determined Contribution (NDC) can be completed ahead of schedule and could even reach its peak around 2025 with increased efforts. In 2018, China's carbon intensity fell about 46% from 2005 levels, two years ahead of the target of achieving a 40 to 45% reduction by 2020[7]. The trend of rapid growth in carbon emissions has been preliminarily reversed.

FIGURE 1.4: GHG EMISSION REDUCTION SCENARIOS UNDER DIFFERENT TEMPERATURE TARGETS



Note: To keep temperature below 2℃ above pre-industrial levels, atmospheric concentration levels of about 450 ppm CO_2eq should be achieved by 2100 and global GHG emissions in 2050 should be reduced by 40% to 70% from 2010 levels.

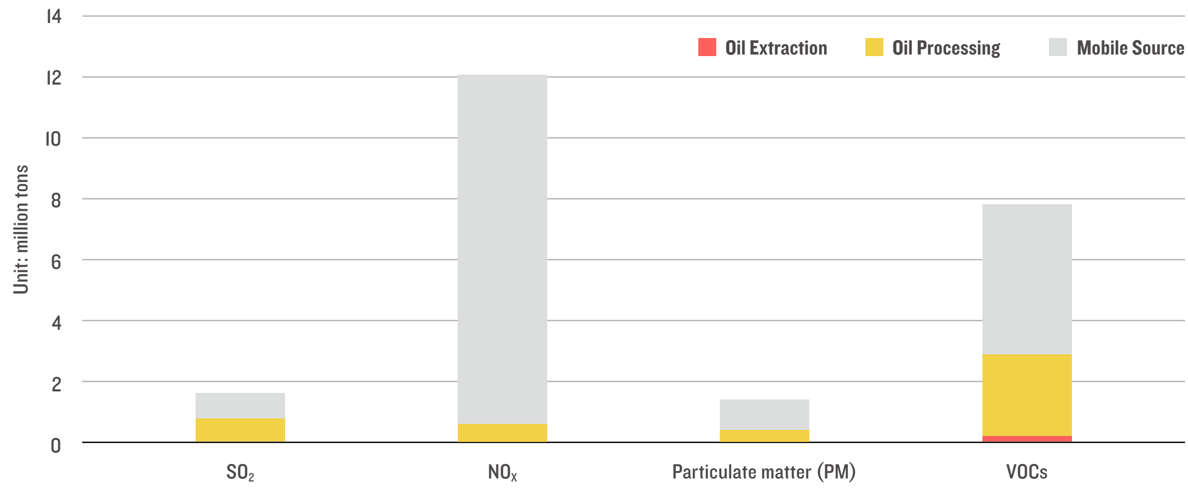
Source: Global Warming 1.5°C Special Report, IPCC, October 2018

[5] 2019-2020 Coal Cap Research Framework, China's coal consumption cap plan and policy research project, May 2019

[6] China's oil consumption peak and cap plan [J], Li Yue et al, China Energy, 2019

[7] Feasibility of China's Intended Nationally Determined Contribution, China Coal Consumption Cap Plan and Policy Research Project, November 2018

FIGURE 1.5: OVERVIEW OF POLLUTANTS PRODUCED BY CHINA'S OIL EXTRACTION, PROCESSING AND CONSUMPTION (2015)



Source: A Study on the True Cost of Oil in China, China Oil Consumption Cap Plan and Policy Research Project, June 2019

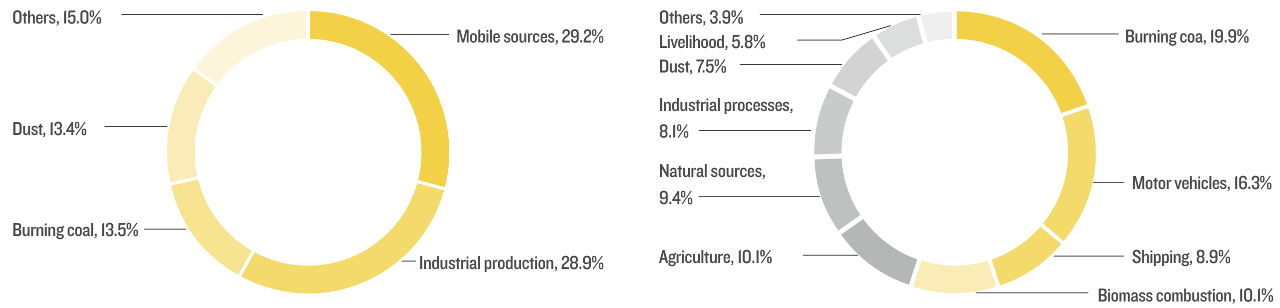
3. BUILDING A "BEAUTIFUL CHINA" WILL REQUIRE DECOUPLING ECONOMIC GROWTH AND OIL CONSUMPTION AS SOON AS POSSIBLE

Treating a pleasant ecological environment as the most important public good and the most inclusive benefit for people's wellbeing, the Chinese government has clearly stated its determination to win "the Battle for Blue Skies" and to accomplish its goal of building a "Beautiful China" by 2035. Despite year-on-year decreases in the emission of major pollutants, China is still struggling with the emission of SO_2, NOx, PM and volatile organic compounds (VOCs) from oil extraction, processing, storage, transportation and consumption. In particular, NOx emissions from oil exploitation and utilization account for over one third of total national emissions, see Figure 1.5. Moreover, the petrochemical sector consumes large amounts of water and discharges large quantities of wastewater that contain a complicated variety of pollutants such as carcinogenic substances and heavy metals, which are difficult to treat and have both short- and long-term impacts on environment and human health. A large number of petrochemical projects are still being planned and developed by many local governments. This will not only make it more challenging to control the emission of VOCs, supply clean water and treat wastewater, but will also create new ecological, environmental and health risks.

Because ICE vehicles still dominate road transportation, many cities in China have started to suffer from the combined pollution of coal smoke and exhaust fumes from motor vehicles that will directly affect public health. The source analysis of $PM_{2.5}$ 15 major cities in China, including Beijing, Shanghai and Guangzhou, shows that local mobile sources contribute 13.5% to 52.1% of $PM_{2.5}$ emissions[8]. Figure 1.6 illustrates $PM_{2.5}$ sources in Shanghai and Guangzhou in 2016. In Shanghai, mobile sources represented 29.2% of $PM_{2.5}$ emissions; in Guangzhou, on-road motor transportation sources and off-road transportation sources such as ships caused 25.2% of $PM_{2.5}$ emissions. As pollutants from other sources are declining, the transportation sector has become an increasing contributor of $PM_{2.5}$ pollution. Among motor vehicles, diesel freight trucks—which represent 7.8% of China's total vehicle population—contribute to 57.3% of NOx and 77.8% of $PM_{2.5}$ emissions, becoming a foremost priority for urban air pollution control. Among non-road mobile sources, construction and agricultural machinery and equipment emit nearly an equivalent quantity of NOx and $PM_{2.5}$ to that of

[8] China Vehicle Environmental Management Annual Report 2018, Ministry of Ecology and Environment of the PRC, May 2018

FIGURE 1.6: AN ANALYSIS OF $PM_{2.5}$ SOURCES IN SHANGHAI (LEFT) AND GUANGZHOU (RIGHT) IN 2016



Sources: Shanghai 2016 Atmospheric Fine Particulate Matter Source Analysis Research Results, Shanghai Environmental Protection Bureau, June 2017; Guangzhou 2016 Atmospheric Fine Paticulate Matter Source Analysis Research Results, Guangzhou Environmental Protection Bureau, June 2017

motor vehicles. In addition, exhaust fumes from ships, which also constitute a major air pollutant source, have increasingly adverse effects on the quality of air in China's coastal areas as well as in river-front and port-hosting places.

The time period from 2013 to 2018 saw a 35% to 45% drop in the emission of major air pollutants such as PM_{10}, $PM_{2.5}$, SO_2 and NOx in China, as well as a slow decrease in VOCs emissions, but an increase in O_3 emissions which rose from 140 $\mu g/m^3$ to 150 $\mu g/m^3$ on average. Ozone has become a major summer air pollutant in big cities, inflicting considerable harm on the health of the general public. The transportation sector is the main source of ozone emissions[9].

4. SAFEGUARDING ENERGY SECURITY REQUIRES APPROPRIATE GUIDANCE ON OIL CONSUMPTION

China's rapid growth in oil consumption and its high import dependence for new consumption constitutes a grave challenge to the country's energy and economic security. In 2018, China imported 1,588.2 billion RMB of crude oil and 133.3 billion RMB of refined oil, growing 43.1% and 35.6% respectively from the previous year. Oil has become one of China's largest commodity imports, behind only integrated circuits[10]. As is shown in Figure 1.7, China's crude oil production increased from 203 million metric tons in 2010 to the peak of 215 million metric tons in 2015, followed by a gradual decline to 189 million metric tons in 2018.

For almost three years China has been 100% dependent on oil imports for its increasing consumption. Overall, China has entered a stage of low-grade oil exploration and development. With effort, China is expected to be able to maintain its annual production at around 200 million metric tons for the time being, but at a cost much higher than that of oil-producing countries in the Middle East. In the future, China will continue to rely on imports for most of its additional oil use, resulting in its growing dependence on foreign oil.

Constant technological breakthroughs in oil/gas exploration and development are also reshaping world oil supply markets. The US became a net importer of oil in 1953. After the peak of domestic oil production in 1970, oil imports increased year by year. The "shale gas revolution" broke the US' dependence on foreign oil and gradually turned the country into a new major oil producer and exporter. In 2018, the US' oil import dependence rate was only 31.8%, the lowest level since 1967[11]. The global energy resource landscape has been profoundly altered, a situation that is compounded by uncertainties caused by competition among the three major players, the US, Russia and Saudi Arabia.

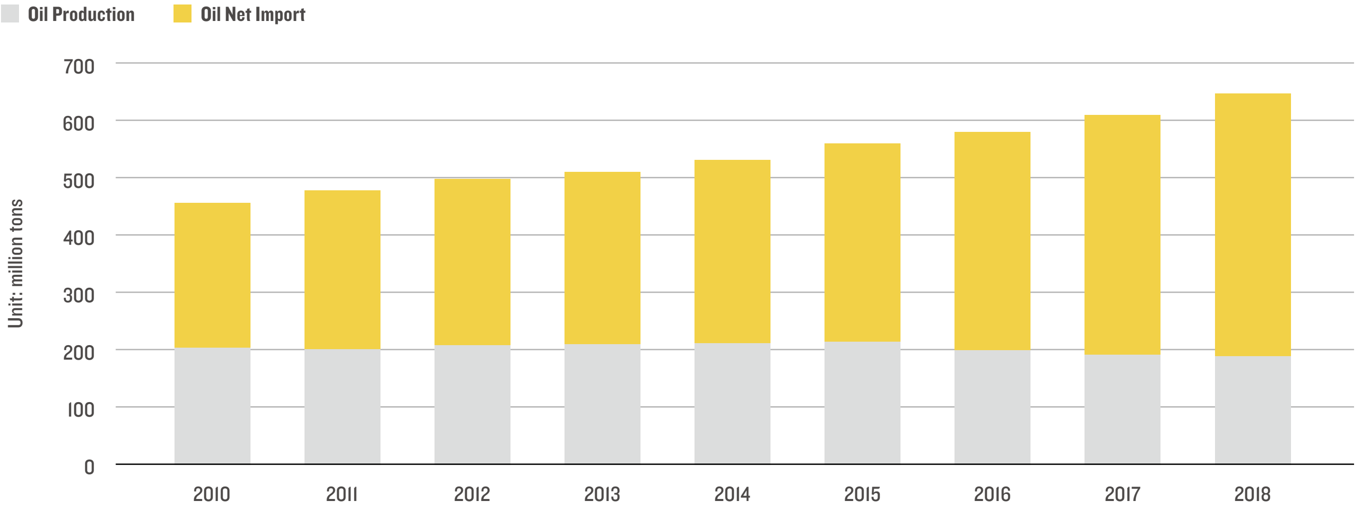
Figure 1.8 illustrates the major sources and quantities of China's

[9] A Study on the True Cost of Oil in China, China Oil Consumption Cap Plan and Policy Research Project, June 2019

[10] China Customs Statistical Yearbook 2018, General Administration of Customs, China Customs Publishing Co., Ltd., July 2019

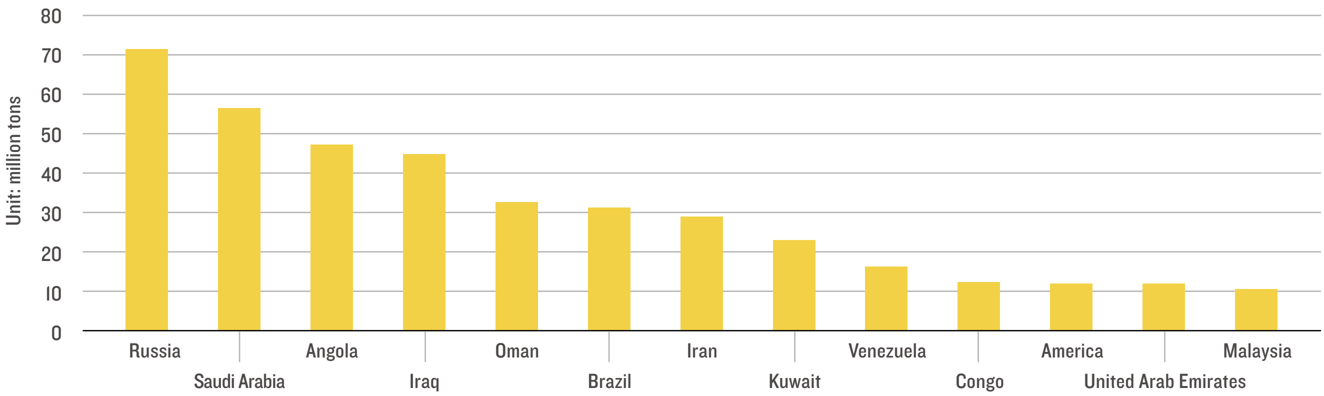
[11] Annual Energy Outlook 2019, US Energy Information Administration, January 2019

FIGURE 1.7: CHINA'S OIL PRODUCTION AND IMPORT (2010-2018)



Source: China Statistics Sumary 2019, Edited by the National Bureau of Statistics, China Statistics Press, May 2019

FIGURE 1.8: THE MAIN SOURCES AND QUANTITIES OF CHINA'S OIL IMPORT IN 2018



Source: BP World Energy Statistical Yearbook 2019, BP, June 2019, 68th Edition

oil imports. Most of these countries are vulnerable to external disruptions, both economically and politically. This means that the higher China's dependence on foreign oil is the more vulnerable its economy will be to these external disruptions. To safeguard its energy security, China must diversify its sources of oil and strengthen its emergency response capabilities in storage and transportation. More importantly, China must improve the efficiency of its oil use, peak its oil consumption earlier, and then achieve a steady decrease in oil consumption so as to reduce its oil import dependence for the sake of its social and economic stability.

5. CHINA IS FACED WITH CHALLENGES IN PEAKING AND CAPPING ITS OIL CONSUMPTION

Of world energy consumption in 2018, oil, coal, natural gas and non-fossil energy sources accounted for 33%, 27%, 24% and 16% respectively[12], with oil remaining the largest energy source. Since the 1950s, the world has moved from the age of coal into the age of oil in terms of energy consumption, with developed countries having peaked their coal, oil and natural gas consumption. Table 1.1

[12] BP World Energy Statistical Yearbook 2019, BP, June 2019, 68th Edition

lists the year, quantity, per capita oil consumption and per capita GDP in various developed countries when they achieved oil peak, comparing to the status quo in China.

The difference in oil consumption among countries is also relatively large, see Figure 1.9. In 2018, the per capita oil consumption in the US was about 2.81 tons, and the per capita GDP was about 63,000 USD. Per capita oil consumption in other developed countries is generally more than 1 ton. The per capita GDP is between 30,000 and 50,000 USD. The history of developed countries shows that the higher the per capita GDP, the higher the per capita oil consumption will be. China is the largest developing country in the world. At present, the per capita GDP is around 9,420 USD, which is 80% of the world average. China's economy and energy demand are expected to continue growing. China's per capita oil consumption in 2018 is 0.45 tons, which is one-fifth of the level in the US and 40% of the level of Britain and France. In addition, it is also lower than the world average level of 0.6 tons.

However, it is often overlooked that China has a coal-based energy structure (coal accounted for 58% of the primary energy consumption in 2018 and oil accounted for 18.9%), while most developed countries have oil-based energy structures. If the per capita oil consumption level is used to illustrate the rationality of China's oil consumption growth potential, it will be quite one-sided. Neither maintaining the existing coal-based energy structure nor emphasizing the growth of per capita oil consumption will eliminate China's dependence on high-carbon energy and reduce China's energy security risks.

If oil were to account for 32% of China's primary energy consumption, equalling around six billion metric tons of coal equivalent, that percentage would mark China's entry into the age of oil with a per capita oil consumption of close to one metric ton. Under such scenario, China will find itself faced with unbearable externalities, such as environmental degradation, overstretched resources, pollutants and carbon emissions, urban noise pollution and traffic congestion.It is clear that, to move forward on its energy transformation journey, China must break its coal dependence, leap over the age of oil and embrace a future of new energy sources.

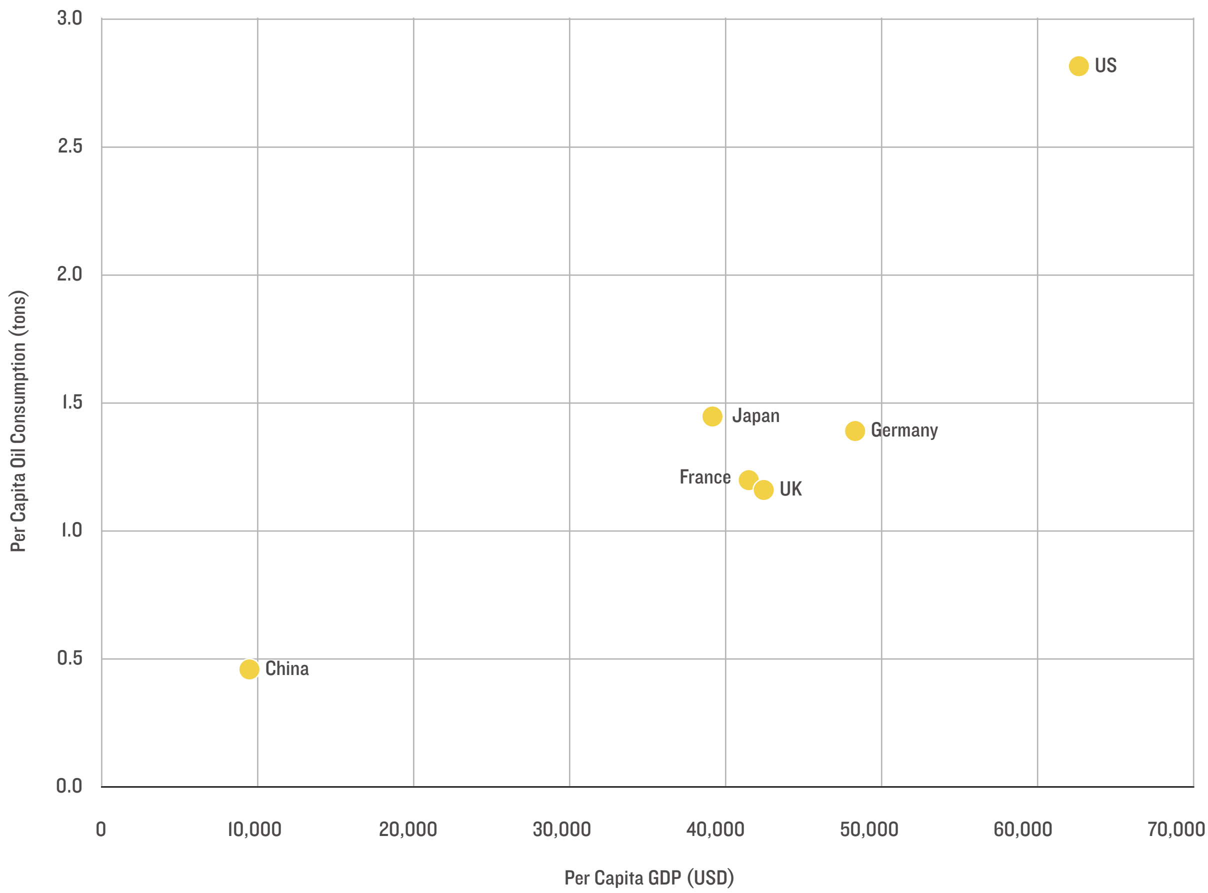
Major developed countries have already peaked their oil consumption and per capita oil use in some developed economies has been declining continuously. China should also establish oil peaking as its primary target and take effective measures to leap over the age of oil. In 2016, China launched a sweeping energy revolution that covers consumption, supply, technology,

TABLE 1.1: COMPARISON OF MAJOR DEVELOPED COUNTRIES AND CHINA'S OIL CONSUMPTION PEAK

	US	GERMANY	FRANCE	UK	JAPAN	CHINA
Oil Consumption Peak Year	2005	1979	1973	1973	1996	-
Oil consumption at Peak (million tons of oil equivalent)	972.7	167.7	129.5	115.6	279.2	-
Oil consumption in 2018 (million tons of oil equivalent)	919.7	113.2	78.9	77	182.4	642
Oil consumption's proportion of primary energy in 2018	40.0%	34.9%	32.5%	40.1%	40.2%	18.9%
Per capita oil consumption in 2018 (tons)	2.81	1.37	1.18	1.16	1.44	0.45
Per capita GDP in 2018 (USD)	62,641	48,196	41,464	42,491	39,287	9,420

Source: International Oil Consumption Trends and Policy Review, Lawrence Berkeley Natioanl Labratory, China Oil Consumption Cap Plan and Policy Research Project, June 2019

FIGURE 1.9: THE CONNECTION BETWEEN PER CAPITA GDP AND PER CAPITA OIL CONSUMPTION IN VARIOUS COUNTRIES IN 2018



Source: International Oil Consumption Trends and Policy Review, Lawrence Berkeley Natioanl Labratory, China Oil Consumption Cap Plan and Policy Research Project, June 2019

institutions and international cooperation, implementing policy guidelines and constraints so as to create a clean, low-carbon, secure, efficient and modern energy system as part of its efforts to promote the shift from extensive energy development to a high-quality one.

In the near future, while satisfying the reasonable, rising oil demand of various regions, China should innovatively carve out a new path to support its goal of building a moderately prosperous and modern society with a much lower oil consumption rate per capita. In main oil-consuming sectors, China can enforce stronger measures to achieve the goals of shifting from increasing to decreasing oil consumption and reducing the use of oil as a fuel and increasing its use as a petrochemical feedstock, as well as creating an energy supply and consumption system dominated by non-fossil energy sources.

2

THE TRUE COST OF OIL CONSUMPTION IN CHINA

The external costs of oil exploitation and utilization have not yet been fully reflected in the existing market system. There is a shared consensus among countries that the true cost of oil exploitation and utilization should be internalized and reflected by the real price. For China, an in-depth analysis of the negative impacts of oil exploitation and consumption on water resources, the water environment, aquatic ecosystems, soil, vegetation, the natural water cycle, climate change, and public health will help to quantify the true cost of oil and provide a basis for government policy making, particularly with regard to environmental taxation and incentives, so that these policies will be more effective and targeted. This will allow companies fulfilling their social responsibilities to predict how much their investment and technology applications will contribute back to society. The general public will also have a clearer idea of how they can make a difference by promoting and engaging in different consumer behaviors.

1. THE ENVIRONMENTAL IMPACTS OF OIL EXPLOITATION AND UTILIZATION

1.1 Water environment impact

Oil exploitation, processing, conversion and consumption will all have serious negative impacts on water resources. When extracting oil, most oil fields will inject large amounts of water to increase pressure. Particularly in northern China, major oil fields are mostly located in arid or semi-arid zones, where water resources are scarce. To satisfy their water demand, large oil fields often divert surface water or extract groundwater. This practice will on the one hand exacerbate already serious water shortages and overstretch local water resources, leading to the over-extraction of shallow and deep groundwater and causing a dramatic lowering of the water table. This would make water increasingly inaccessible and would disrupt local peoples' lives and work in the region. On the other hand, in terms of the geographic distribution of oil and water resources, China's oil resources are concentrated in eight basins—Bohai Bay, Songliao, Tarim, Erdos, Ordos, Junggar, the Pearl River Delta, Qaidam and the East China Sea Shelf. Since most of these basins are water-poor, unregulated oil extraction practices may threaten the protection and sustainability of water resources. According to existing data, the average water consumption of oil extraction is 2.8 cubic meters per ton of oil[13].

TABLE 2.1: POLLUTANTS FROM INDUSTRIAL WASTEWATER DISCHARGED BY OIL-RELATED SECTORS & RANKING IN KEY SURVEYED SECTORS

SECTOR	OIL PROCESSING, COKING & NUCLEAR FUEL PROCESSING		CHEMICAL RAW MATERIALS & CHEMICAL PRODUCTS MANUFACTURING	
	QUANTITY DISCHARGED (TONS)	RANKING	QUANTITY DISCHARGED (TONS)	RANKING
COD	-	-	346,000	2
Ammonia	15,000	3	58,000	1
Petroleum	2,738	1	2,086	2
Volatile phenol	790.8	1	85	2
Cyanid	58	1	40	2

Source: 2015 China Environmental Statistics Annual Report, Beijing Xinhua Press, December 2015

[13] Where did industrial wastewater go, China Petroleum Daily, May 17, 2019

The negative impacts of oil extraction on the water environment are often caused by three types of pollution—infiltration, penetration, and accidents. Infiltrative and penetrative pollution usually results in nonpoint-source pollution including diffuse contamination of surface, soil and ground water, whereas accidents often cause point-source pollution. The water injection that is practiced in prospecting, drilling and extraction damages the regional natural water cycle and consumes large amounts of water. In addition, crude oil spills and wastewater reinjection into the wrong stratum will also seriously contaminate surface, soil and ground water, thus indirectly causing ecological degradation. In northeast China, for example, major pollutants from heavy industry and oilfield development, such as ammoniacal nitrogen, nitrate nitrogen and nitrite nitrogen ("the three nitrogens") as well as petroleum-derived pollutants, have severely polluted ground water. The three nitrogens, volatile phenols and petroleum pollutants are also common in the Songliao Plain. China is rich in shale gas as well as in tight oil and gas. If these resources are developed on a large scale, close attention must be paid to the environmental harm and cost associated with the infiltration and surface treatment of the water used in hydraulic fracturing for unconventional oil and natural gas.

Water-consuming sectors also include sectors closely related to oil consumption, such as oil processing, coking and nuclear fuel processing, as well as raw chemical materials and chemical products manufacturing. Wastewater discharged by these sectors often affects the quality of their neighboring water bodies. In 2015, the amount of water drafted by companies from oil-related sectors reached 6.76 billion cubic meters, representing 10% of the amount used by industrial companies above a designated size (ICADS) (referring to industrial companies with a yearly revenue of 20 million RMB). Among them, the raw chemical materials and chemical products sectors accounted for 7.1%; the oil processing, coking and nuclear fuel processing sectors, 1.5%; the oil and gas extraction sector, 1.3%, ranking 1st, 10th and 12th among ICADS in terms of amount of water drafted[14], as shown in Figure 2.1. Wastewater from the petrochemical sector contains a complicated variety of substances, often including cancer-causing pollutants and heavy metals, which are difficult and costly to treat. Inspections by Chinese environmental authorities reveal that some petrochemical companies have caused serious environmental pollution by illegally discharging untreated or substandard wastewater.

Oil spills and leaks resulting from offshore oil exploitation and maritime crude oil transportation can cause huge financial losses to sectors such as marine fishing and farming, coastal tourism, and maritime transportation, as well as damage to the marine environment and effect adverse changes in marine ecosystems. A study shows that more than 10 million metric tons of various oil products, or about 0.5% of the world's annual oil output, are released into the sea every year due to human activities, such as industrial discharges, oil leaks from ships, accidents, offshore oil fields, and incidents like blowouts[15]. It's estimated that China releases approximately 1.28 million tons of oil substances into the sea every year.

Moreover, the extensive use and careless discard of plastic products also constitutes a serious threat to the environment. According to a report from the United Nations Environment Programme (UNEP), the world produced 8 to 9 billion tons of plastics between 1950 and 2015, generating tens of millions of tons of plastic waste every year (the figure varies significantly from source to source). Of all the plastic waste ever produced, 79% has accumulated in landfills, dumps or the natural environment, 12% has been incinerated and only 9% has been recycled[16]. By 2025, the amount of plastic waste in global oceans will amount to 250 million tons, 28% of which will be caused by China[17]. Plastic debris can float and thus cause diffuse pollution. When exposed to ultraviolet light, they can break into smaller pieces that will not biodegrade. When concentrated in large quantities, plastic debris in the ocean will also cause harm to marine life like zooplankton by devouring marine organisms. When plastic substances are eaten by fish, they will work their way into the human food chain and therefore cause greater

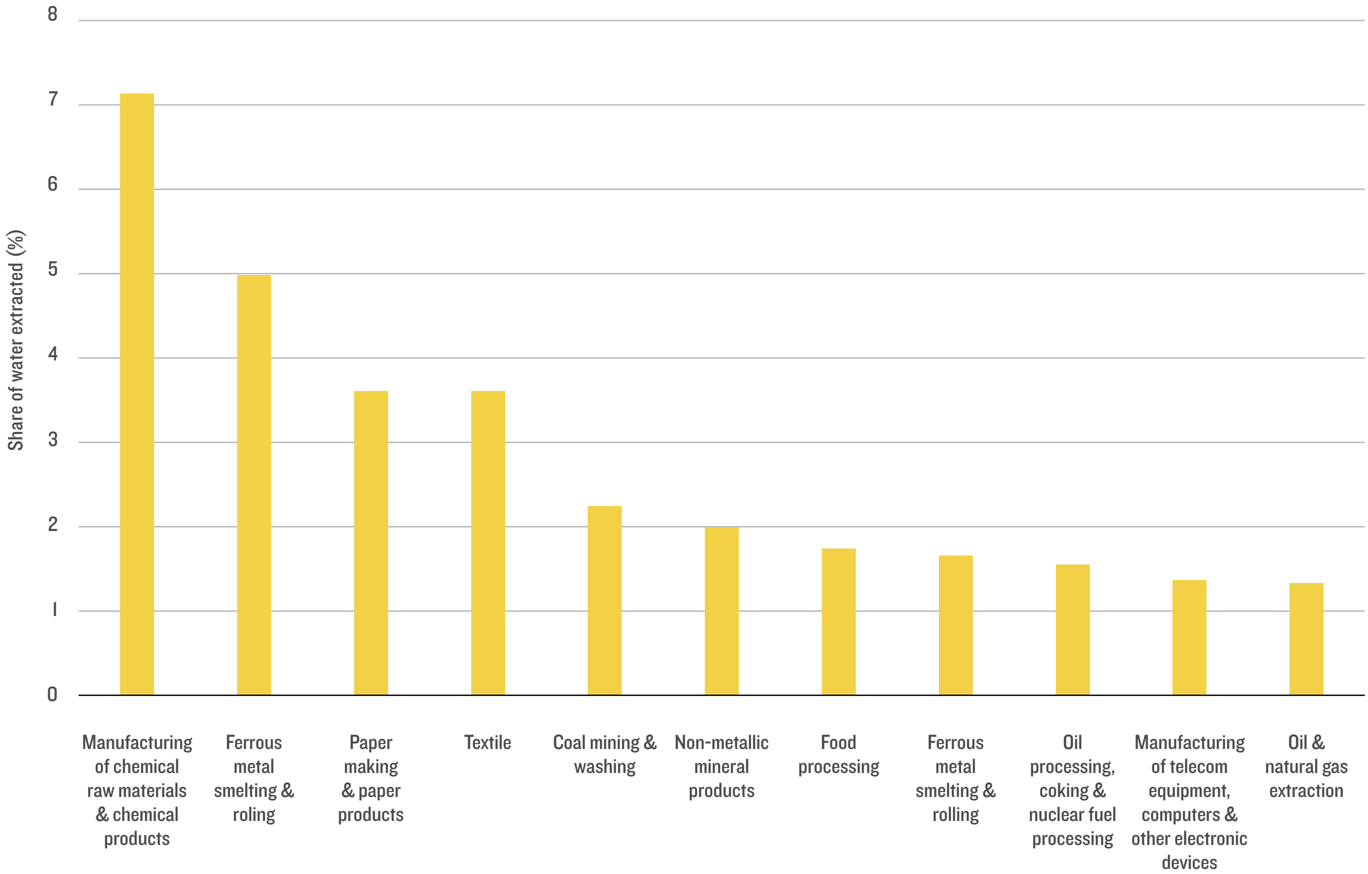
[14] A Study on the External Cost of Water Resource During Oil Utilization, China Institute of Water Resources and Hydropower Research, China Oil Consumption Cap Plan and Policy Research Project, June 2019

[15] Liu Xianjie, Study on the Impacts of Oil Spill Accidents on Polycyclic Aromatic Hydrocarbons in the Marine Environment, Dalian Maritime University, 2016

[16] Banning Disposable Plastics: Lessons and Experiences from National Experiences, UNEP, 2018

[17] China Environmental Statistics 2015, China Environment Press, Ministry of Environmental Protection

FIGURE 2.1: SHARE OF WATER EXTRACTED BY ICADS BY SECTOR



Source: Research on the External Costs on Water Resources of Oil Extraction and Utilization, China Institute of Water Resources and Hydropower Research, China Oil Consumption Cap Plan and Policy Research Project, June 2019

harm—through biological magnification—to humans at the top of the food chain.

1.2 Atmospheric environment impact

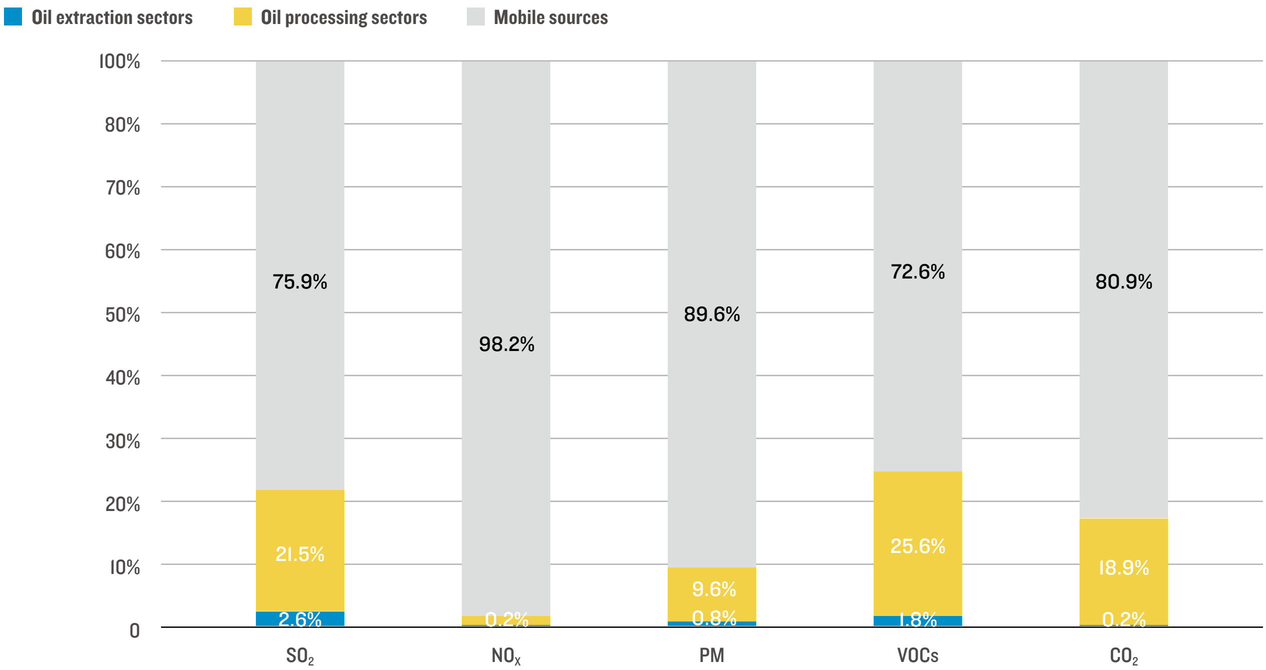
Air pollutants caused by oil extraction mainly include fumes from coal-fired boilers used for heavy oil thermal recovery and exhaust gas emissions from oil/gas processing, collection and transmission systems, which generate a variety of greenhouse gases and air pollutants including VOCs, SO_2, NOx, and particulate matter (PM). These are major precursors of $PM_{2.5}$ and O_3 pollutants.

According to official data, China emitted 11.713 million tons of NOx, 6.796 million tons of VOCs, 1.146 million tons of PM and 1.112 million tons of SO_2 in 2015 as a result of oil extraction, processing and consumption. It is also estimated that CO_2 emissions from oil extraction, processing and consumption contributed 11% of the national total. NOx, VOCs, PMs and SO_2 emissions from mobile sources, followed by oil processing and extraction sectors, respectively represent 98.2%, 72.6%, 89.6% and 75.9% of total such emissions from oil-related sectors[18], as shown in Figure 2.2.

An assessment of the impact of pollutants from oil-related sectors on average annual concentrations of $PM_{2.5}$ using an air

[18] Ministry of Environmental Protection, China Environmental Statistics 2015, China Environment Press

FIGURE 2.2: PERCENTAGE OF POLLUTANTS CAUSED BY DIFFERENT SEGMENTS OF THE OIL INDUSTRY



Source: A Study on the True Cost of Oil in China Consumption Cap Plan and Policy Research Project, June 2019

quality simulation model shows that, of the average $PM_{2.5}$ level in 2015, 10.9% stemmed from oil extraction, processing and consumption, 1.1% from the petrochemical sector, and 9.8% from mobile sources.

1.3 Soil environment pollution

Oil drilling cannot be done without creating drilling fluid, and this fluid seriously pollutes the soil environment. Nearly every oil drilling rig will create a mud crater covering an area of around two acres. Drilling fluid residues then solidify and are buried on site, and they are often not treated seriously by environmental protection requirements. However, given the vast area of oil and gas exploration and development, there are now waste fluid pools all over China, and the total amount of solid waste mud is staggering. If not handled properly, the time and cost of processing this waste will increase exponentially. Oil companies should invest a large amount of funds designated specifically for this processing.

Despite the importance of and demand for land resources and increasing environmental protection awareness there is still continuous damage due to existing solidified drilling waste. While it is required that mud not be buried and that the mud treatment process be carefully regulated and monitored with compliance solutions, large-scale adoption of these practices has not yet come to fruition. Additionally, the problem of the original mud pits has not been solved, a particular challenge in China where there are a large number of existing and new mud pits. In 2015, China produced 215 million tons of crude oil. It is estimated that there are hundreds of thousands of working oil wells. In addition to old wells and natural gas wells, it is estimated that there are at least one million wells, occupying a large amount of land. Treating mud at new wells and reprocessing and repairing old wells will come at significant cost.

Oil extraction and processing are also likely sources of crude oil leaks, including oil products and oil-water mixtures, which cause soil pollution and thus cause adverse effects for water bodies and vegetation in surrounding areas. The most serious soil pollution is usually caused by crude oil leaks from wells as well as of water-based drilling fluids. Other incidents that may cause soil pollution include oil well blowouts and leaks, pipeline leaks, the release of crude oil to the ground near oil fields, oil/gas leaks from petrochemical factories and the leak of water-based drilling fluids. Additionally, large-scale extraction of oil and groundwater will result in larger areas of salinized and alkalinized soil which causes land subsidence. As a result, local precipitation cannot flow or be channeled away and can only evaporate. This means that salt content accumulates on the surface of the land which expands and aggravates soil salinization and alkalization. Oil processing also produces a variety of industrial solid waste, which mainly includes waste catalysts, waste absorbents and ceramic balls, as well as coal combustion residuals and domestic waste from power plants. Without proper management, hazardous substances contained in solid waste will cause harm to the environment and human health. The manufacturing of petrochemical products will also generate large amounts of hazardous solid waste that must be professionally and centrally treated. Unfortunately, hazardous waste is also often hidden underground, causing serious contamination to water bodies, air and soil, thus threatening local lives.

1.4 Pubic Health impact

Chinese oil products are mostly consumed by on-road mobile sources like motorized vehicles, as well as by non-road mobile sources such as construction machinery, agricultural machinery, small general machinery, ships, railways and planes. Exhaust fumes from these mobile sources contain NOx, VOCs, PM and hydrocarbons, which can harm human respiratory, cardiovascular, nervous, immune, reproductive and other systems. Among these pollutants, exposure to $PM_{2.5}$ can significantly increase the risk of contracting diseases in respiratory, circulatory and reproductive systems, exposure to O_3 can dramatically raise the incidence, hospitalization rate and mortality of cardiovascular and respiratory diseases, and exposure to VOCs can adversely affect human respiratory, nervous and immune systems and may even cause cancer and genetic diseases.

Findings from the Oil Cap Research Project show that in 2015, oil-related air pollution caused an excess death toll of 195,000 and 150.68 billion RMB in financial losses in China. In 74 major cities (see Figure 2.3), oil-related air pollution caused an excess death toll of 74,000 and 88.89 billion RMB in financial losses. By region, these

© Photo by Danilo Martinez Gonzalez on flickr

FIGURE 2.3: GEOGRAPHICAL DISTRIBUTION OF CHINA'S 74 MAJOR CITIES

Source: Analysis of the Health Impacts of a China Oil Cap, China Oil Consumption Cap and Policy Research Project, June 2019 two figures respectively stood at 16,000 and 16.08 billion RMB in the Beijing-Tianjin-Hebei city cluster, 21,000 and 32.44 billion RMB in the Yangtze River Delta city cluster, and 6,000 and 8.9 billion RMB in the Pearl River Delta city cluster. The combined health cost caused by oil-related air pollution in these three regions, which are the most economically prosperous and densely populated in China, amounted up to 57.42 billion RMB, representing 64.6% of the total of the 74 major cities[19]. This means that the three regions have borne the biggest brunt of oil-related air pollution.

Moreover, the production, consumption and disposal of plastic, a major product of the petroleum industry, will also have a negative impact on the environment and pose risks to human health. For example, plastic consumption and disposal, particularly the incineration of plastic waste, will release into the air a variety of hazardous substances that will threaten the health of animals, plants and humans, such as heavy metals, dioxins, organic compounds like furan, and polycyclic aromatic hydrocarbons. Hazardous substances such as microplastics and chemical additives, when released into the environment, can directly or indirectly enter the human body to cause reproductive and endocrine disorders and even cancer. In addition to conventional pollutants, heavy metals, chemical components and carcinogens cause great harm to human health. In areas where the chemical sector is clustered water pollution is severe, and water pollution prevention is urgent. There are several studies showing that air pollution will become a bigger global killer than water pollution. So maybe it's best to change the tone of the sentence to make it more neutral: water pollution can be more harmful to human health than air pollution, and its effects are longer lasting.

© Photo by Baumerk Construction Chemicals on flickr

1.5 Climate change

In 2015, oil extraction, processing and consumption in China resulted in the emission of 1.016 billion metric tons of CO_2. Measured in monetary terms, climate change has caused considerable losses, harm and risks to the global environmental and marine ecosystems, biodiversity, mankind's productive activity, life and health. This study shows that the production, processing and consumption of one metric ton of oil will result in the emission of 1.88 metric tons of CO_2. In addition, oil production, transportation and storage will produce and release methane and other greenhouse gases. In oil extraction and processing, gas flaring also burns off 2.2 cubic meters of per metric ton of oil.

2. FRAMEWORK AND METHODOLOGY FOR ASSESSING THE EXTERNAL ENVIRONMENTAL COSTS OF OIL

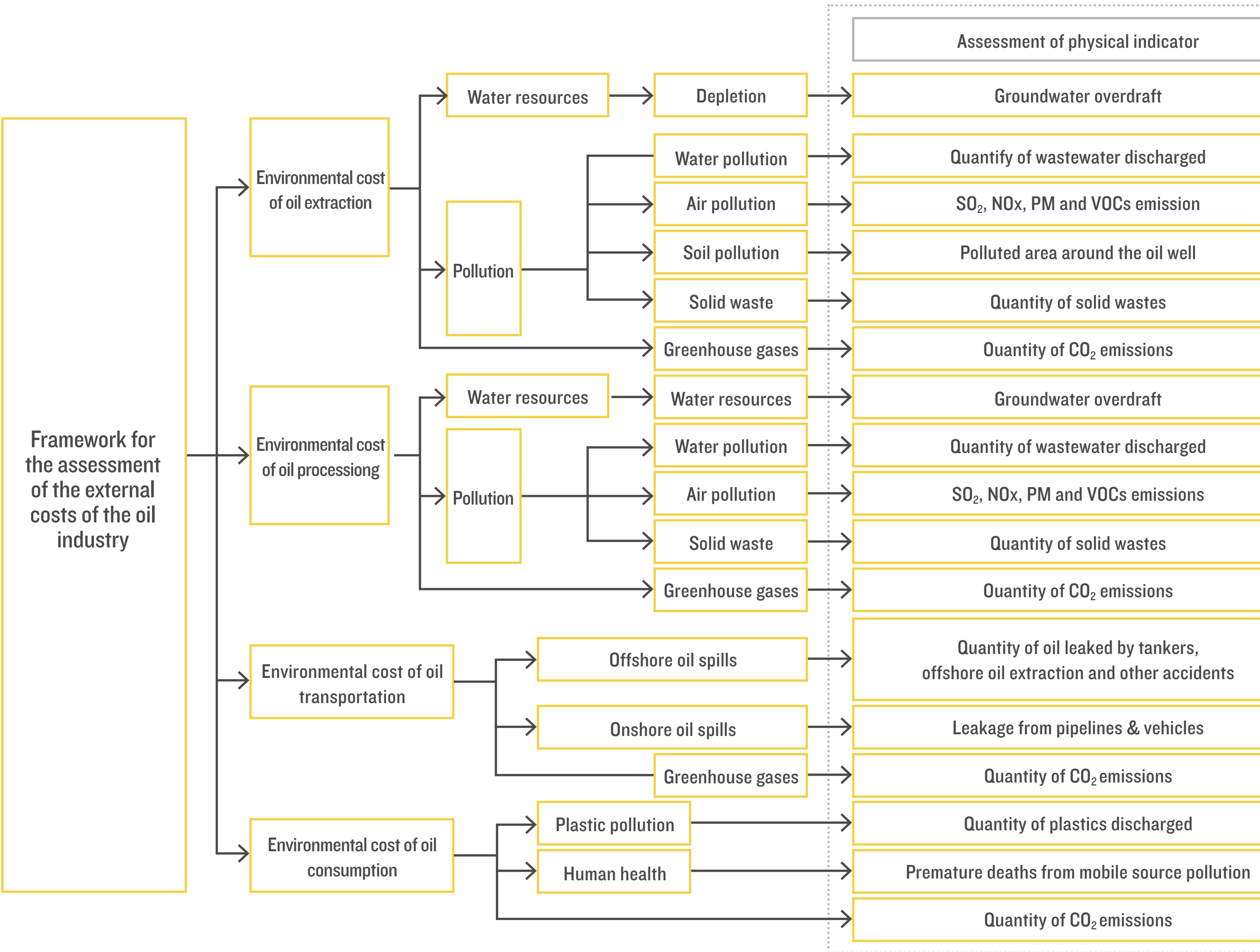
2.1 Assessment framework

In oil extraction and processing, the study mainly factors in the costs of water resource depletion, water pollution, soil pollution, the emission of air pollutants and the discharge of solid waste (the impact of accidents such as explosions in petrochemical and chemical companies is not considered due to the inaccessibility of data). In oil transportation, the study focuses on the cost of accidents in oil tanker transportation and

19 A Study on the True Cost of Oil in China, China Oil Consumption Cap Plan and Policy Research Project, June 2019

offshore oil exploitation as well as the cleanup cost of marine oil spills, without regard for the cost of marine ecosystem restoration, ecological losses during the restoration period and other costs (the cleanup cost of onshore oil spills is too low to be considered and relevant data is hardly accessible, so the cost is not covered). In oil consumption, the study mainly assesses the cost of the impact of oil consumption-caused pollutants on human health, the impact of plastic pollution on marine ecosystems, and the impact of plastic recycling, incineration, discard, or being piled up in landfill on the air, water and soil (because of the lack of a reliably defined exposure-response relationship between health and water pollution caused by oil extraction, processing and consumption as well as the lack of relevant statistical data, the health cost of water pollution is not calculated) (see Figure 2.4).

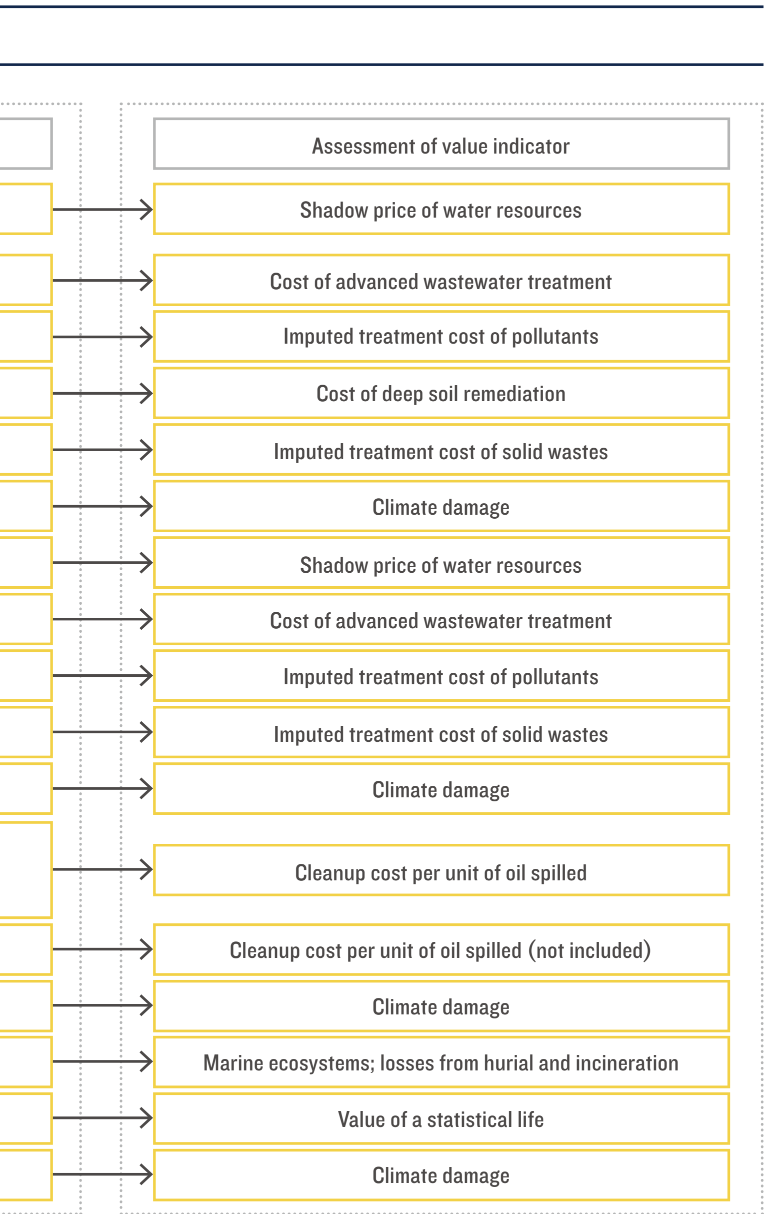
FIGURE 2.4: THE FRAMEWORK AND INDICATORS USED TO ASSESS THE ENVIRONMENTAL EXTERNAL COSTS OF OIL



Source: The True Cost of Oil, China Oil Consumption Cap Plan and Policy Research Project, June 2019

2.2 Assessment methodology

Assessing the external cost of oil mainly factors in nine environmental costs caused by oil extraction, transportation, processing and consumption—water resource depletion, water pollution, air pollution, soil pollution, solid waste pollution, oil spills, plastic pollution, human health impact and CO_2 emissions. Specifically, the cost can be calculated using the formula below:



$$C_{oil} = \sum_{i=1}^{9} D_i * P_i$$

In this formula, C_oil represents the environmental cost of oil use; D_i represents the physical indicator of the impact of Item i caused by the use of a metric ton of oil; P_i represents the value indicator of the impact of Item i caused by a metric ton of oil.

In terms of cost assessment of water resource depletion, we can—from the perspective of resource sustainability—assess the impact of oil development exploitation and use on overdraft and measure the cost of the process of extracting groundwater for crude oil extraction and refining purpose beyond the aquifer's capacity for self-restoration. The shadow price of water can be combined with the industrial sharing coefficient to determine the value of a particular unit of water.

The control cost method is employed to assess the environmental cost of water pollution, air pollution, solid waste pollution, oil spills and plastic pollution. This means that pollutants are treated in accordance with certain standards before released into the environment and the spending on the treatment or reduction of such pollutants is deemed as the control cost. The restoration cost method is used to measure the environmental cost of soil pollution. When pollutants released into nature exceed the self-purification capacity of soils, they will cause harm to the environment. To prevent such harm or deterioration, certain improvement measures can be taken to lift the quality of the polluted soil to meet certain standards. The spending on this restoration effort is the restoration cost.

When measuring the health cost of pollution, we first estimate the impact of $PM_{2.5}$ and O_3 pollution caused by oil use and then adopt the willingness to pay (WTP) method, based on the exposure-response relationship between a particular health outcome and pollution, to calculate the human health cost caused by air pollution as a result of oil consumption.

Calculating the cost of CO_2 emissions mainly involves the assessment of the impact of global warming on climate change as a result of CO_2 and CH_4 emissions caused by oil production, transportation, processing and consumption. Using the current mainstream model to estimate the social cost of global carbon

TABLE 2.2: THE EXTERNAL ENVIRONMENTAL COSTS OF OIL EXTRACTION, PROCESSING AND CONSUMPTION[Notes 1]

SEGMENT	TYPE		INDICATOR	Environmental cost of a unit of oil consumed (RMB/ton)[Note2]
Oil extraction	Water resources	Water resources	Quantity of groundwater over-extracted, shadow price of water resources	6.6(16.6)[Note3]
	Environmental	Water pollution	Quantity of wastewater discharged, cost of advanced wastewater treatment	1.9(4.9)
		pollution	Quantity of pollutants emitted such as SO_2, NOx, PM and VOCs, imputed treatment cost	2.4(6.1)
		Soil pollution	Polluted area around the oil well, cost of deep soil remediation	1.1(2.8)
		Solid waste pollution	Quantity of solid wastes stored and discharged, imputed treatment cost	0.1(0.3)
			Total	12.1(30.7)
Oil transportation	Maritime transportation	Oil spills	Quantity of oil spilled, cleanup cost	1.2 (The average cleanup cost of an oil spill is between 78.12 and 76589.29 USD)[Note4]
Oil processing	Water resources	Water resources	Quantity of water over-extracted, shadow price of water resources	1.8
	Environmental pollution	Soil pollution	Quantity of wastewater discharged, cost of advanced wastewater treatment	1.8
		Air pollution	Quantity of pollutants emitted such as SO_2, NOx, PM and VOCs, imputed treatment cost	33.5
			Quantity of solid wastes stored and discharged, imputed treatment cost	0.2
			Total	37.3
Oil consumption	Environmental pollution	Plastic pollution	Marine ecosystem; air, water, soil and other losses due to burial and incineration	17.4
		Human health loss due to air pollution	Premature deaths, average value of a statistical life	278.6(181.7-423.7)
			Total	296(199.1-441.1)
Total without climate impact				346.6(249.7-491.7)
Climate impact		CO_2 emissions	Climate damage	160.7(160.7-782.1)
Total with climate impact				507.3(410.4-1273.8)

Notes: 1. The factors that are not covered in the assessment of the environmental cost of oil include: 1) the impact of offshore oil extraction on marine ecosystems; 2) the impact of ecological losses caused by marine ecosystem remediation and restoration due to marine oil spills; 3) the environmental impact of onshore oil spills; 4) the environmental impact of accidents such as explosions in petrochemical and chemical companies; and 5) the value of health loss caused by water pollution.

2. The environmental cost of oil listed in the table represents the cost of an average metric ton of oil consumed.

3. The bracketed value represents the cost of pollution caused by a unit of oil extracted to water resources, water environment and soil.

4. Due to different factors such as the type, scale and treatment method of oil spills as well as varying labor costs, treatment techniques and prices in different countries, the treatment cost of a unit of oil spilled varies between 78.12 USD and 76,589.29 USD.

5. For the cost estimation uncertainty analysis, please refer to the *A Study on the True Cost of Oil in China* published online in June 2019 by the China Oil Cap Project.

emissions (taking account of the harmful effects of climate change on the whole world, not just China), the social cost will be between 160.7CNY/ton of oil – 782.1CNY/ton of oil. This report uses the low estimate of 160.7CNY/ton of oil and uses it as the per-unit CO_2 emission cost.

3. RESULTS OF ENVIRONMENTAL COST ASSESSMENT

Our cost assessment results show that if the climate impacts of oil production, processing and consumption are not considered, the external environmental costs of oil extraction, processing and consumption in China were 347 RMB per metric ton in 2015. This figure rises to 507 RMB per metric ton if such climate impacts are factored in. In 2015, China respectively consumed 543 million and extracted 215 million metric tons of oil, which means that the external environmental costs of oil development exploitation and use in China amounted to approximately 275.5 billion RMB that year. When we examine the environmental costs by segment of the oil value chain, we find that in the oil extraction segment, water resource depletion and water pollution constitute the major cost components, representing 70.2% of the segment's total external costs; in the oil processing segment, due to the unavailability of statistical data, we exclude the costs of water resource depletion and water pollution caused by the chemical sector that uses petroleum as a raw material, and focus our environmental cost estimation on air pollution; in the oil consumption segment, health loss caused by air pollution is the biggest source of external cost, accounting for 94.1% of the segment's total external costs.

3

SCENARIO ANALYSIS OF CHINA'S OIL CONSUMPTION

There are numerous factors that affect oil consumption and its trends. They not only include macro-economic factors—such as population size, economic output, levels of urbanization and industrialization—and sectoral factors—such as levels of car ownership, transportation structure and the development level of the petrochemical industry, but more importantly, pathway choices such as energy development strategy, environmental and climate policy. On the basis of summing up major factors affecting oil consumption in various countries, this report uses a systematic analysis model to create different oil consumption scenarios in China from 2015 to 2050 and offers an analysis of their main characteristics and conclusions.

I. FACTORS AFFECTING OIL CONSUMPTION

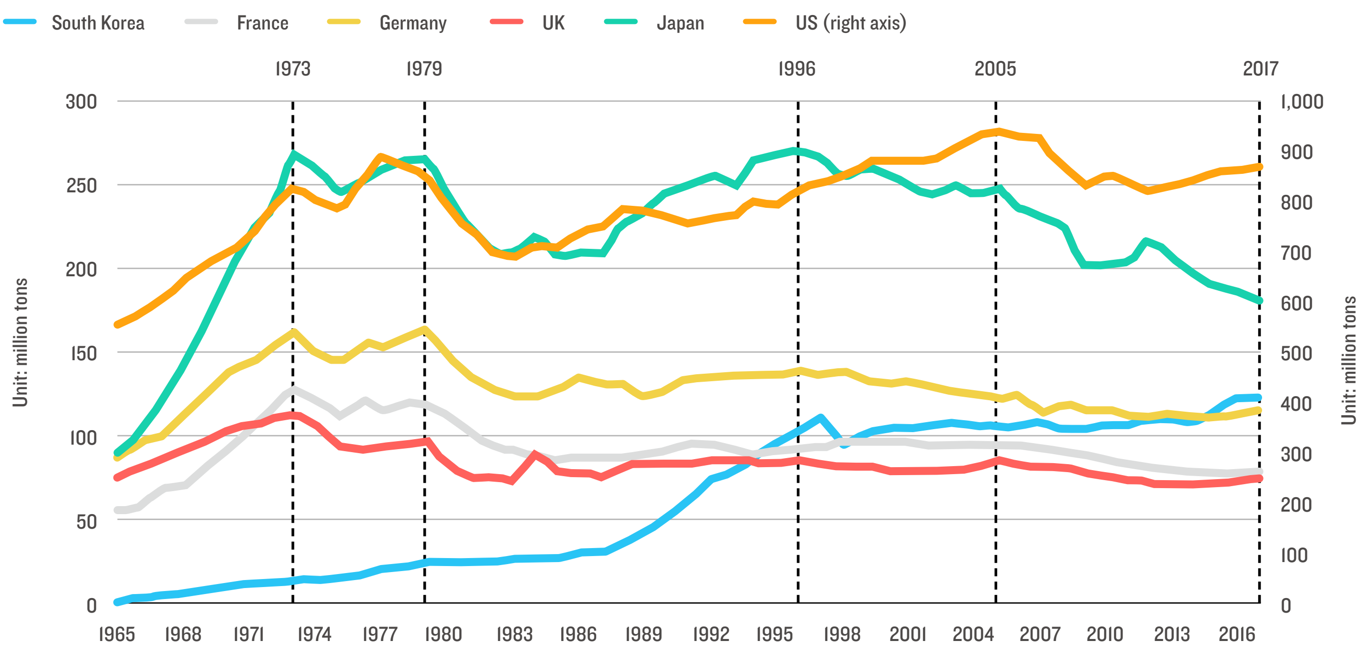
1.1 Economic development levels and living standard requirements are the major factors affecting total oil consumption

The experience of developed countries shows that oil consumption rises in tandem with growing economies and improvements to living standards. When an economy reaches a certain level of development, its oil consumption will reach a peak and will then decline. Britain and France peaked their oil consumption when their per capita GDP was 4,000 to 5,000 USD; Germany, 11,000 USD; the US and Japan, 43,000 to 45,000 USD .

In the past when developed countries have achieved peak oil consumption, they had all completed industrialization, with a shrinking share of industry in their GDP and accelerating structural adjustments in industry. When the US, Britain and France reached peaks in oil consumption, their industrial output accounted for about 20% of GDP; Germany and Japan, about 30%; South Korea, about 40% . Major developed countries were all at the later stage of industrialization when peaking their oil consumption, but countries like South Korea still experienced oil consumption growth after completing industrialization because of the larger share of the petrochemical sector in GDP at the later stage of industrialization.

Economic cycles also have an effect on oil consumption. The global financial crisis in 2008 pushed the world economy into a recession, causing oil consumption to quickly decline in developed countries. Oil consumption is also closely related to the energy mix within oil-consuming sectors. Transportation and petrochemicals are two such sectors. A transportation structure dominated by fuel and an industry structure heavily relying on petrochemicals will keep oil consumption at a high level.

FIGURE 3.1 CHANGES AND PEAKS IN OIL CONSUMPTION IN MAJOR DEVELOPED COUNTRIES



Source: A Study on China's Oil Consumption Scenarios (2018-2050), Sinopec Economics & Development Research Institute, China Oil Consumption Cap Plan and Policy Research Project, June 2019

[20] A Study on the True Cost of Oil in China, China Oil Consumption Cap Plan and Policy Research Project, June 2019

1.2 Policy intervention can cause shifts in peak oil consumption and pathways

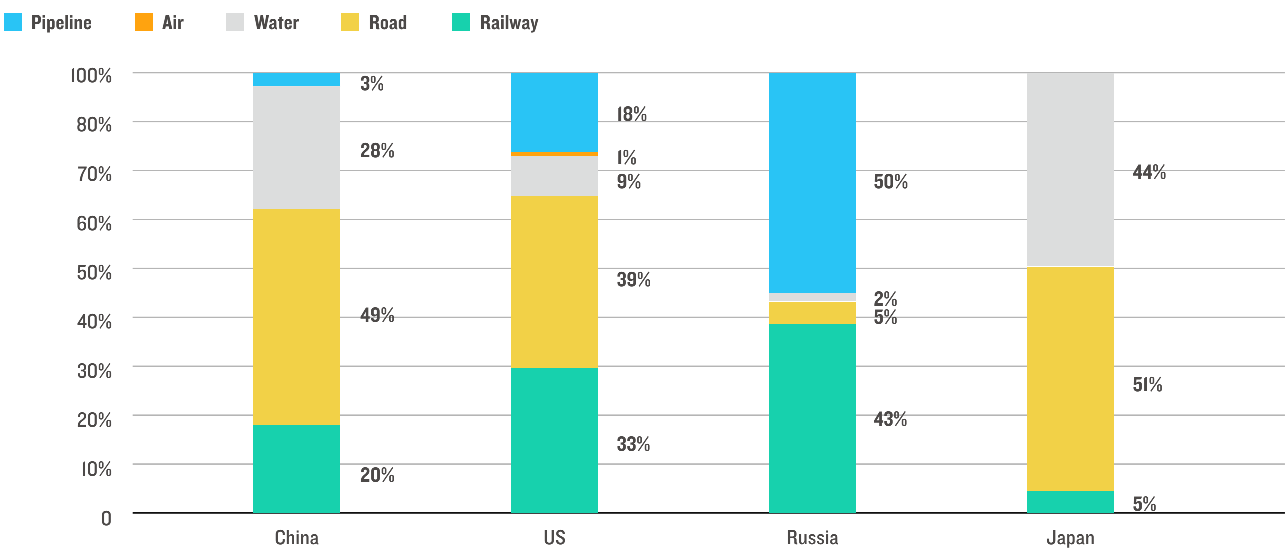
The two oil crises in 1973 and 1979 rapidly pushed up oil prices, hitting developed economies hard and changing the trajectory of their oil consumption. During this period, developed countries showed two "camel humps" in their oil consumption (see Figure 3.1). Ensuring oil supply security has since become one of the most important energy strategies. After the 1979 oil crisis, developed countries in Europe saw a steady decline in oil consumption.

In response to the oil crisis, OECD (Organization for Economic Cooperation and Development) countries established the International Energy Agency (IEA) in an attempt to improve energy efficiency and increase strategic oil reserve. In particular, the IEA made policies to develop fuel economy standards and a fuel tax for vehicles, which resulted in marked shifts in oil consumption patterns. In Europe and Japan, the imposition of a fuel tax pushed up oil prices by 100% to 120%; in the US, about 25%. In China, fuel tax now accounts for approximately 30% of oil prices[21]. In 1995, due to its economic stagnation, leading vehicle fuel efficiency standards and declining international trade, Japan reached its second peak in oil consumption and experienced a continuous decline thereafter. In 2004, the US Congress approved stricter fuel efficiency standards that had been shelved for 20 years, which caused its oil consumption to reach its second peak in 2005 and a continuous decline thereafter. Oil consumption in South Korea fell about 1% in 2018 compared to 2017, but it remains to be seen whether 2017 will be a peak year. Developed countries mostly brought about peak oil through rigorous policy interventions when they had serious international political and economic crises or when they were faced with challenges in growing their economies. Althougth strategic oil reserve, fuel tax and stricter fuel economy standards did not break these countries' dependence on oil, these measures have effectively reduced oil consumption. In this process, alternative fuels were also a contributor.

1.3 The important role of transportation modes and structures in the transportation sector

In 2017, the transportation sector accounted for 57.7% of oil use. Transportation mode and the level of motorized vehicle ownership are the two key factors affecting peaking oil

FIGURE 3.2: STRUCTURE OF TRANSPORTATION IN DIFFERENT COUNTRIES (2017)



Source: A Study on China's Oil Consumption Scenario Analysis (2015-2050), Sinopec Economics & Development Research Institute, China Oil Consumption Cap Plan and Policy Research Project, June 2019

[21] Review of International Oil Consumption Trends and Policies, Lawrence Berkley National Laboratory, China Oil Consumption Cap Plan and Policy Research Project, June 2019

consumption. In terms of oil consumption per capita, the more road transportationation is used and the higher level of car ownership per 1,000 people, the higher oil consumption per capita will be.

In road transportation in China, medium- and heavy-duty trucks offer much room for improvement in terms of transport and oil efficiency. Currently, the share of road transportation in China's total freight turnover is close to 50% compared to less than 20% of railway transportation. The ratio of road to railway transportation is 2.5, which is much higher than that of the US (1.2) and Russia (0.1), both of which are also very large countries. This means that for China, there is a lot of potential for improvement in transportation efficiency (see Figure 3.2). By optimizing and adjusting its transportation structure, China can pivot on railways and waterways to transport commodity goods and passengers over long distances, while increasing the shares of pipeline and air transportation. This will significantly reduce the share of road transportation.

In 2016, the car ownership per 1,000 people was more than 800 vehicles in the US and 400 to 600 vehicles in Europe. By contrast, the number of vehicles per 1,000 people in China was only about 140 in the same year (see Table 3.1). With people's growing travel needs, China will see this number continue to expand. If China does not replace oil with alternative energy sources or improve oil efficiency, it will find it a daunting challenge to achieve peak oil.

The adoption of advanced technology to improve vehicle oil efficiency can also help save large amounts of oil. Thanks to the growing importance China attaches to energy efficiency and environmental protection, vehicle fuel economy has been constantly rising. The Ministry of Industry and Information Technology's *Energy-Saving and New Energy Vehicles Industry Development Program* sets a goal of cutting average fuel consumption by passenger car to 5L/100 km by 2020, to 4.5L/100 km by 2025 and further to 3.2L/100 km by 2030; in terms of average fuel consumption by commercial vehicle, the goal is to bring it close to international advanced levels by 2020, reach international advanced levels by 2025 and become a global leader by 2030. The goal has already factored in oil consumption that will be offset by NEVs, so average fuel consumption by ICE vehicles will be higher than the targets set above.

Apart from vehicle fuel efficiency standards, consumer behaviors and preferences, such as the preference of large SUVs and the average kilometers driven per year, will also affect oil consumption. In this regard, average oil consumption per vehicle in the US is much higher than that of Europe, Japan and South Korea.

1.4 Car ownership per 1,000 people is a key indicator for the road transportation sector

Among the multitude of indicators, car ownership and its structure are significant for peak oil. According to the historical oil consumption data of developed countries, the saturation level of car ownership has a direct bearing on gas and diesel peaks, and improved fuel economy will bring forward peaks and reduce fuel consumption. Generally, vehicles can be divided into passenger vehicles and commercial vehicles. The former is closely related to per capita income, reflecting people's improved standard of living, whereas the latter correlates with economic growth, particularly with industrial production.

In developed countries or regions, when per capita GDP reaches 20,000 to 30,000 USD, the saturation level of car ownership mostly ranges from 370 to 660 vehicles per 1,000 people. In the US, Canada, Britain and Japan, this saturation level stands between 600 and 800 vehicles per 1,000 people, compared with a range of 400 to 600 in most European countries. In densely populated regions where car ownership is strictly controlled, such as Hong Kong and Singapore, the saturation level is between 100 and 200 vehicles per 1,000 people.

Another significant factor affecting fuel demand is average kilometers driven per year. According to two sample surveys conducted by the Sinopec Economics & Development Research Institute in 2002 and 2010, The average passenger car was driven 17,000 km per year in 2002 (with swept volume distribution and weighted purposes of traveling), which dropped, at an average yearly pace of 0.8%, to 16,000 km per year in 2010. The use of passenger cars is related to household consumption. Given China's steadily rising performance in this area, the figure is expected to drop to 14,000 km per year by 2020. From 2030 onwards, the increased penetration of shared cars will further reduce the yearly mileage of passenger vehicles.

TABLE 3.1: CAR OWNERSHIP AND PENETRATION BY COUNTRY/REGION IN 2016

	PER CAPITA GDP (USD)	VEHICLES PER 1,000 PEOPLE	POPULATION DENSITY (NUMBER/SQ KM)	POPULATION (MILLION)	TOTAL VEHICLE ONWERSHIP (THOUSAND)
China	8,123	140	147	1,379	193,060
US	57,467	800	35	323	258,400
Germany	41,936	572	237	82	46,900
Japan	38,895	591	348	127	75,060
South Korea	27,539	376	526	51	19,180
Hong Kong (China)	43,681	116	6,619	7	810
Taiwan (China)	22,540	300	638	24	7,200

Source: World Bank Open Data; The International Organization of Motor Vehicle Manufacturers (OICA)

The long-term growth potential of commercial vehicles correlates with the level of economic development and industrialization of a country. In the early stage of industrialization, the number of commercial vehicles usually grows faster than GDP; in the middle stage, in tandem with GDP; in the later stage, slower than GDP. Today, China already has more passenger buses (excluding minibuses) per 1,000 people than developed countries. In the future, high-speed railways will also be increasingly used by Chinese people for short-distance travels. The only source of growth for large and medium-sized buses will be the growing public transport bus service needed by cities whose populations are still expanding year on year, as well as rapidly growing logistical services in cities. Generally, commercial vehicles are expected to reach a saturation level of approximately 48 million between 2020 and 2030, when freight trucks will represent a slightly larger share of commercial vehicles.

Table 3.1 shows the number of vehicles per 1,000 people of various countries in 2016. For China, this number will be gradually pushed up by its people's growing travel needs. If it does not resort to alternative energy sources or fails to improve oil efficiency, the country will find it more challenging to achieve peak oil.

1.5 Petrochemical sector growth remains uncertain

The petrochemical industry is the second largest oil-consuming sector. The development of the petrochemical sector, especially shifting international divisions of labor, is a signficiant driver of oil consumption. The experience of developed countries shows that, following peak oil in the transportation sector, the different pathways chosen by countries for petrochemical sector development will affect their oil demand. Due to growing demand for chemical products like alkenes and paraxylene, British and French per capita oil consumption continuously fluctuated during their peak period and British and German per capita oil consumption rebounded significantly after reaching their peaks. Compared with these countries, Chinese per capita consumption of chemical products remains low, which means that strong demand in the future will drive up oil consumption.

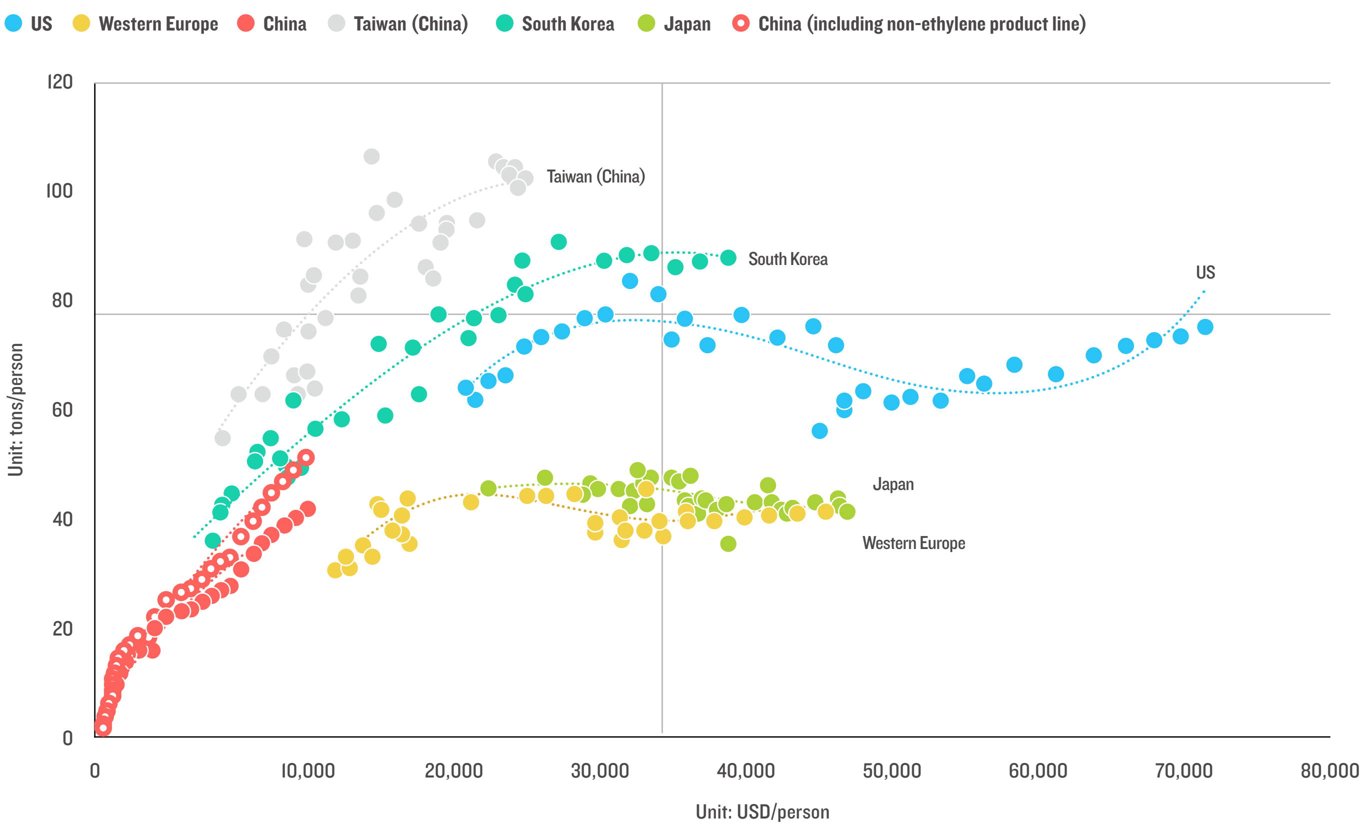
As shown by Figure 3.3, Taiwan and South Korea exported large amounts of petrochemical products, with per capita ethylene equivalent consumption much higher than that of Western Europe and the US. Western European and Japanese per capita consumption of ethylene equivalent has been stable, while US per capita ethylene equivalent consumption is nearly 100% higher than that of Western Europe and Japan. China is expected to slightly trail Western Europe and Japan on this indicator.

China's supply-side structural reform of the petrochemical sector, which aims to improve energy efficiency, optimize industry structure, diversify sources of raw materials and restructure international trade, will also have a great impact on oil consumption. Looking into the future, other uncertain factors that will affect oil consumption include improved energy efficiency in the petrochemical sector, the use of alternative energy sources such as natural gas, biomass and hydrogen energy, and restrictions on plastics.

1.6 Addressing constraints imposed by climate change and air pollution control

Amid the global fight against climate change, all countries are accelerating their transformation towards green, low-carbon energy sources. In November 2018, the European Commission released a strategic long-term vision—*A Clean Planet for All*, which lays out goals to create a climate neutral EU by cutting

FIGURE 3.3: CORRELATION BETWEEN PER CAPITA GDP AND ETHYLENE EQUIVALENT CONSUMPTION



Source: A Study on China's Oil Consumption Scenario Anlysis (2015-2050), Sinopec Economics & Development Research Institute, China Oil Consumption Cap Plan and Policy Research Project, June 2019

GHG emissions by 40% by 2030, 60% by 2040 and achieving net-zero GHG emissions by 2050. Some European and Asian countries and/or regions have also introduced timetables and pathways for the phase-out of traditional ICE vehicles. Major developed countries are pushing for a green, low-carbon transformation of energy production and consumption systems on both supply and demand sides, thus tightening constraints on global growth in oil consumption.

At the same time, the $PM_{2.5}$ concentrations must be lowered to 10 μg/m^3 to meet the WHO's air quality criteria. When trying to improve air quality, cities find that vehicles' exhaust fumes are one of the biggest sources of air pollution. Table 3.2 lists the timetables of some countries and regions for phasing out traditional ICE vehicles. It's noteworthy that some of these timetables are part of national bills, some verbally proposed by government officials, and some already mandated by government documents. The timetable released by the Hainan Provincial Government of China in March 2019 is a local mandatory requirement. In our scenario analysis, such timetables are important policy options. Fuel substitution technologies like electrification also play major roles in reducing oil consumption in the transportation sector.

TABLE 3.2: TIMETABLES FOR THE PHASE-OUT OF ICE VEHICLES IN VARIOUS COUNTRIES, REGIONS, AND CITIES

COUNTRY/REGION/CITY	YEAR OF PROPOSAL	WAY OF PROPOSAL	DEADLINE	SCOPE OF VEHICLES
Netherlands	2016	Bill	2030	Passenger petrol/diesel vehicles
Norway	2016	National plan	2025	Petrol/diesel vehicles
Paris, Madrid, Athens, Mexico City	2016	Joint announcement by majors	2025	Diesel vehicles
Germany	2016	Bill	Est. 2030	ICE vehicles
France	2017	Verbally proposed	2040	Petrol/diesel vehicles
UK	2017/2018	Verbally proposed/Transportation	2040	Petrol/diesel vehicles
Scotland (UK)	2017	Government document	2032	Petrol/diesel vehicles
India	2017	Verbally proposed	2030	Petrol/diesel vehicles
Ireland	2018	Verbally proposed	2030	Petrol/diesel vehicles
Israel	2018	Verbally proposed	2030	Imported passenger petrol/ diesel vehicles
Italy (Rome)	2018	Verbally proposed	2024	Diesel vehicles
Hainan (China)	2019	Government document	2030	Petrol/diesel vehicles
Taiwan (China)	2017	Government action plan	2040	Petrol/diesel vehicles

Source: A Study on China's Timetable for Phasing Out Traditional ICE-Vehicles, Innovation Center for Energy and Transportation, China Oil Consumption Cap Plan and Policy Research Project, May 2019

2. SCENARIO ANALYSIS OF CHINA'S OIL CONSUMPTION

In this study, scenario analysis was adopted to simulate oil consumption demand in China under different scenarios by setting different model parameters and conditional assumptions from perspective such as growth drivers, environmental constraints, energy security and new energy opportunities. The scenarios examined by the study include the "baseline" scenario, the "strengthened policy" scenario and the "2°C target" scenario, which are respectively defined as follows:

The baseline scenario describes what will happen to oil-related industries under current policies, industry development plans and goals. Under this scenario, oil is consumed to satisfy economic development needs. Driven by the reform of oil and natural gas sectors as well as by policies regarding energy efficiency and the development of NEVs, all the industries mostly follow the existing pathway and trend in the pursuit of their development goals.

The strengthened policy scenario defines what oil consumption will be like in China when stricter oil control policies are enforced in oil-related industries in addition to the impact of current policies and their spillover effects. Under this scenario, China will enact policies to optimize its transportation structure; promote energy diversification and substitution in the transportation sector; restructure and upgrade the petrochemical sector; control over-rapidly growing dependence on foreign oil by implementing certain policies on the import and export of petroleum products and raw materials; safeguard energy security; and pursue its ecological civilization goals through green, low-carbon development.

The 2°C target scenario characterizes China's future oil consumption and demand in its pursuit of the target to keep the global temperature rise this century well below 2°C. Under this scenario, China will actively involve itself in the global fight against climate change and stand a 60% chance of achieving the 2°C target. To fulfill this target and relevant constraining conditions, all sectors must achieve peaks in carbon emissions as early as possible and work hard towards the 1.5°C and carbon neutrality targets.

The study combines "top-down" and "bottom-up" approaches to a detailed analysis of major oil-consuming sectors, including transportation, petrochemical and other sectors, as well as of future demand for various petroleum products such as petrol, diesel and naphtha. The parameters of the three scenarios are detailed in the annexed Table 1.

3. MAIN CONCLUSIONS FROM THE OIL CONSUMPTION SCENARIO ANALYSIS

Based on hypotheses under different variables, constraining conditions and policy options, the three scenarios produce a number of conclusions that establish a solid basis for our analysis regarding the development of an oil cap pathway for China

3.1 Outlook for China's oil demand under the three scenarios

Table 3.3 lists our outlook for China's oil demand in different time periods under the three scenarios.

TABLE 3.3: OUTLOOK FOR CHINA'S OIL DEMAND UNDER DIFFERENT SCENARIOS (UNIT: MILLION TONS)

SCENARIO	2020	2025	2030	2040	2050
Baseline	650	740	770	780	770
Strengthened policy	640	720	720	670	600
2°C target	640	670	650	560	470

Source: China Oil Consumption Scenario Analysis (2015-2050), Sinopec Economics & Development Research Institute, China Oil Consumption Cap Plan and Policy Research Project, June 2019

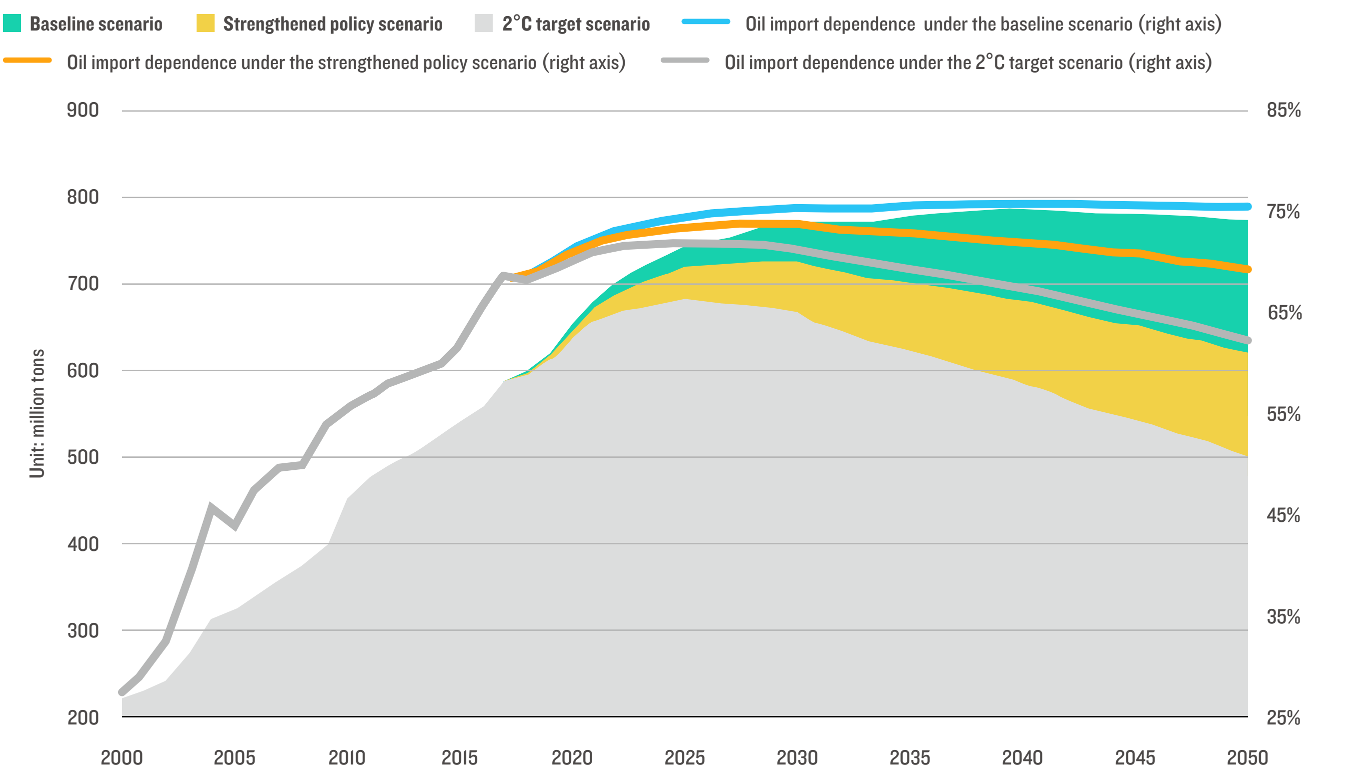
Under the three scenarios, the year China peaks its oil demand advances, with each peak level lower than the previous one (see Table 3.3). Under the baseline scenario, China's oil demand will continue to rise and peak at 780 million metric tons by 2040, and then reach a plateau during the 2040-2050 period and finally gradually slow to 770 million metric tons by 2050. Under the strengthened policy scenario, China's oil consumption will continue to rise at a slower pace and reach a peak plateau of 720 million metric tons during 2025-2030. It will then decline to 600 million metric tons by 2050. Under the 2°C target scenario, China's oil consumption will continue to grow at a slow speed and peak at 670 million metric tons by 2025 and drop to 470 million metric tons by 2050. The oil consumption structure varies significantly from scenario to scenario, with oil consumption in the transportation decreasing significantly and oil consumption in the petrochemical sector continuing to increase. Other sectors are similar to the transportation sector, showing a falling trend in oil consumption, but at a much slower rate.

In terms of China's oil import dependence, under the baseline scenario, when China achieves peak oil by 2040, its dependence on foreign oil will be 76% and will then decline to 75% by 2050; under the strengthened policy scenario, when China achieves peak oil in 2025, its oil dependence will be 73% and then fall to 69% by 2050; under the 2°C target scenario, the figure will be 72% by 2025 and then drop to 60% by 2050. It's noted that China's foreign oil dependence is calculated based on its peak oil consumption year and its domestic oil production is presumed to stay at 2 million metric tons.

3.2 China's main indicators will be close to those of developed countries when its oil demand peaks under the strengthened policy and 2°C target scenarios

From a macro-economic point of view, China's rate of high-quality economic development has reached a medium-to-high speed, its energy-saving and efficiency improvement policies

FIGURE 3.4: OUTLOOK FOR CHINA'S OIL DEMAND AND OIL IMPORT DEPENDENCE UNDER THE THREE SCENARIOS



Source: China Oil Consumption Scenario Analysis (2015-2050), Sinopec Economics & Development Research Institute, China Oil Consumption Cap Plan and Policy Research Project, June 2019

are being effectively implemented, its strategic oil reserves are increasing, its oil efficiency standards driven by the "dual-credit" scheme are leading the world, taxation tools like the fuel tax have curbed the over-rapid growth of oil consumption, and the production and sales of traditional ICE vehicles is reaching a plateau. There has been a nascent wave of growth for vehicles powered by alternative fuels and electricity. Globally, China's trade frictions with the US and other countries are causing world economic growth to stagnate. All these developments are similar to the driving factors experienced by developed countries around the time of peak oil.

Under the baseline scenario, China's oil demand will peak at 780 million metric tons around 2040, with per capita oil consumption standing at 0.55 metric tons. By then, China's per capita GDP will be 28,600 USD and the number of vehicles per 1,000 people will be 390, both surpassing those of major developed countries at the time of peak oil.

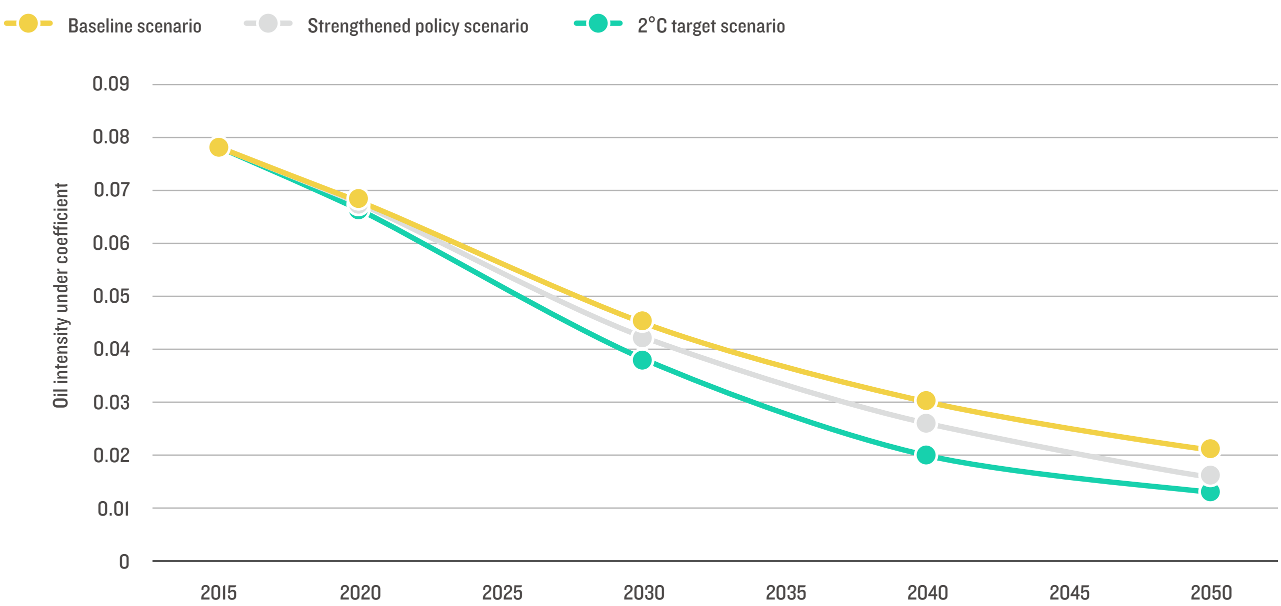
Under the strengthened policy scenario, China's domestic oil demand will peak at 720 million metric tons between 2025 and 2030, with a per capita oil consumption of 0.5 metric tons. By then, its per capita GDP will reach 14,500 USD and the number of vehicles per 1,000 people will stand at 260, both close to those of major developed countries at the time of peak oil. To achieve its targets under this scenario, China will have to implement more rigorous policies to curb oil consumption in relevant sectors.

Under the 2°C target scenario, China's oil demand will peak at 670 million metric tons by 2025, with a per capita oil consumption of 0.47 metric tons, a per capita GDP of USD 14,200 USD and 180 vehicles per 1,000 people. When it reaches peak oil, China's per capita GDP will be close to that of major developed countries, but the number of vehicles per 1,000 people will be much lower. To accomplish the targets under this scenario, energy and other sectors must make concerted efforts and certain sectors will have to impose more restrictive measures.

3.3 Oil consumption intensity will drop dramatically

Compared with historical data, oil efficiency, driven by technological and managerial progress, has been constantly improving, which means that oil intensity, or oil consumption

FIGURE 3.5: OUTLOOK FOR CHINA'S OIL INTENSITY UNDER THE THREE SCENARIOS



Source: China Oil Consumption Scenario Analysis (2015-2050), Sinopec Economics & Development Research Institute, China Oil Consumption Cap Plan and Policy Research Project, June 2019

TABLE 3.4: PERCENTAGE OF OIL CONSUMED BY THE TRANSPORTATION AND PETROCHEMICAL SECTORS BY COUNTRY IN 2016

	US	GERMANY	FRANCE	UK	JAPAN	SOUTH KOREA	CHINA
Percentage of oil used by the transportation sector	77%	58%	61%	72%	46%	35%	54%
Percentage of oil used as feedstock	15%	20%	18%	13%	19%	53%	15%

Source: Review of International Oil Consumption Trends and Policies, Lawrence Berkley National Laboratoy, China Oil Consumption Cap Plan and Policy Research Project, June 2019

per unit of GDP, will decline continuously. Between 2015 and 2050, the cumulative oil intensity will fall 73% under the baseline scenario; by 79% under the strengthened policy scenario; and by 83% under the 2°C target scenario (see Figure 3.5). It should be noted that oil efficiency improvement necessitates the support of technology R&D application and capital markets as well as institutional reforms and managerial progress. For China, technology innovation, particularly NEV development, is of paramount importance.

3.4 The share of oil used by the transportation sector will decline, whereas the share of oil consumption by the petrochemical sector will expand

When breaking down oil consumption in developed countries, we find that the bulk of oil is consumed by the transportation sector, followed by the petrochemical sector. In Europe and the US in 2016, for example, over 60% of oil was consumed by the transportation sector and over 15% was used as feedstock for the petrochemical sector; in Japan, these two percentages respectively stood at 46% and 19%; in South Korea, 35% and 53% (see Table 3.3).

China is now similar to the above-mentioned developed countries in oil consumption structure, but its overall energy mix and serious oil supply shortage requires it to firstly reduce the transportation sector's oil consumption and unlock room for growth of oil as petrochemical feedstock. Under the three scenarios, the share of the transportation sector's oil consumption continuously shrinks, while the share of the petrochemical sector's oil consumption continuously expands. These trends are increasingly reinforced in the ascending order of the baseline, strengthened policy and 2°C target scenarios.

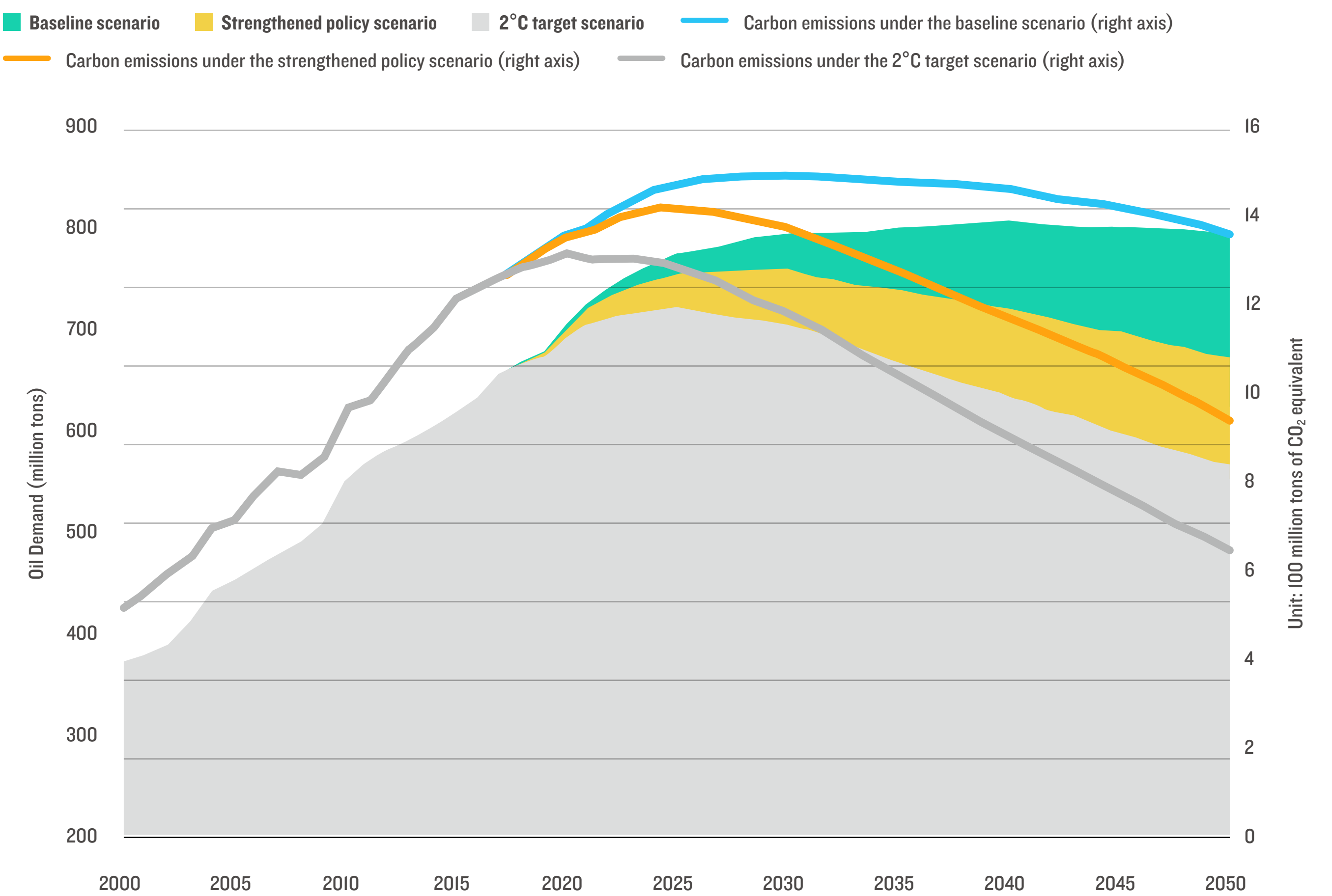
For example, under the strengthened policy scenario, from 2017-2030 improved fuel economy and substitution with NEVs and ethanol fuel will partly offset the increase in oil consumption resulting from expanding vehicle ownership, shrinking the share of the transportation sector's oil consumption to about 47%. The rapid development of ethylene and paraxylene projects will result in growing use of oil in the petrochemical sector, with its share of oil consumption expanding from 15% to 25% (including naphtha and part of liquefied gas). Due to substitution by natural gas and electricity, industrial oil consumption will fall from 12% to 7%.

From 2030-2050, due to the increasing maturity of NEV technology and its rapidly expanding market share as well as the entry of China's automotive industry into an ultimate saturation level, vehicle ownership growth will significantly slow down and the share of the transportation sector's oil consumption will plummet to 36%. The petrochemical sector will continue to grow, but at a slowing pace, with petrochemical oil consumption rising to 35% (including naphtha and part of liquefied gas). The shares of industrial, civilian and agricultural oil consumption will remain basically unchanged.

3.5 Carbon emissions caused by oil consumption will be much lower under the 2°C target scenario than under the baseline scenario

Though the percentage of petrochemical oil consumption continues to rise, the use of petroleum as feedstock or for non-combustion purposes will produce very small amounts

FIGURE 3.6: OUTLOOK FOR CHINA'S OIL DEMAND AND CARBON EMISSIONS UNDER THE THREE SCENARIOS



Source: China Oil Consumption Scenario Analysis (2015-2050), Sinopec Economics & Development Research Institute, China Oil Consumption Cap Plan and Policy Research Project, June 2019

of CO_2 emissions, thus allowing China to see a downward trend in carbon emissions per unit of oil consumption. Under the three scenarios, carbon emissions will peak earlier than oil demand. Under the baseline scenario, carbon emissions from oil consumption will reach a peak by 2030; under the strengthened policy scenario, by 2025; under the 2°C target scenario, by 2020. All three scenarios will see carbon emissions declining at different rates after peaking. It is estimated that oil consumption produced 188 million metric tons of carbon emissions in China in 2017. By 2050, the three scenarios will respectively see an increase of 8% and reductions of 24% and 44% in carbon emissions from oil consumption (see Figure 3.6).

4

CHINA'S OIL CAP PATHWAY AND IMPLEMENTATION ROADMAP

Peaking and reasonably controlling oil consumption is one of the key priorities for China's energy transformation in the short and medium term. Based on scenario analysis, this chapter aims to determine a pathway for capping China's oil consumption (hereinafter "the oil cap pathway") and set the oil cap targets for different time periods—of accomplishing the 14th Five-Year Plan (2025), the "Beautiful China" vision (2035) and the centennial goal of national rejuvenation (2050). The development and implementation of the oil cap pathway will ensure the fulfillment of these targets.

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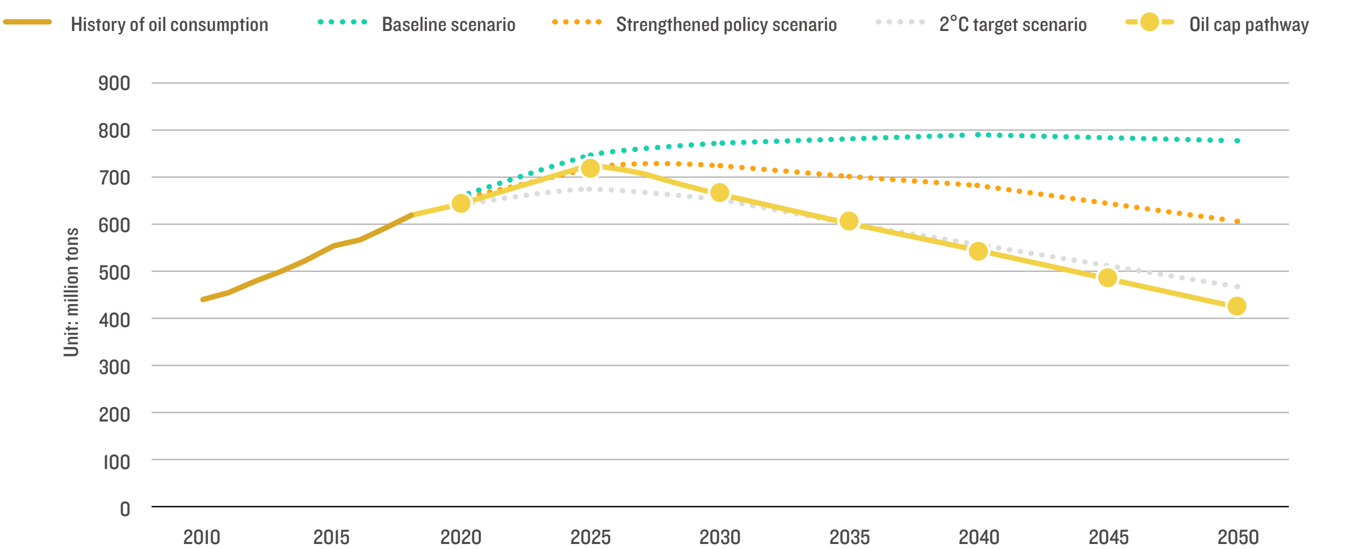
1. DETERMINING AN OIL CAP PATHWAY AND PEAKING OIL CONSUMPTION

The oil cap pathway was determined based on a comprehensive analysis of the three scenarios, including factors such as reasonable growth in oil demand, ecological and environmental constraints, climate change response, industrial changes and technological innovation. Due to the characteristics of the scenario analysis model, the amount of oil consumption under the three scenarios varies from stage to stage. After several rounds of discussion with senior specialist groups, the project team did not just select one particular scenario from the scenario analysis model as China's oil cap pathway, but determined the pathway using a holistic approach.

As shown in Figure 4.1, the curve of the oil cap pathway overlaps with the curve of the strengthened policy scenario from 2018 to 2025, with China's oil consumption peaking at 720 million metric tons by 2025. From 2025 to 2035, the oil cap pathway curve basically follows the curve of the 2°C target scenario towards the "Beautiful China" vision, which is to be fulfilled in 2035, when China's oil consumption will total 600

FIGURE 4.1: OIL CAP PATHWAY DETERMINATION BASED ON SCENARIO ANALYSIS



Source: A Study of China's Oil Consumption Peak and Cap Pathways and Measures (for internal use) , Energy Research Institute of the National Development and Reform Commission, China Oil Consumption Cap Plan and Policy Research Project internal report million metric tons. From 2035 to 2050, by following a pathway that consumes less oil than under the 2°C target scenario and actively implementing various measures, China will peak its oil consumption at 420 million metric tons by 2050 and stand an over 50% chance of achieving the 1.5 °C target.

From the present to 2025, China must make efforts to carry out policies and measures as dictated by the strengthened policy scenario and rely on capping oil consumption as the major cornerstone of its effort to advance energy transition. In addition, it should aim to win "the Battle for Blue Skies" and slow down the overall oil consumption growth. This means peaking oil consumption at 720 million metric tons by 2025 and shrink the share of oil in primary energy consumption to 19.4%.

Between 2025 and 2035, all of China's policy efforts should be upgraded from the strengthened policy to the 2 °C target scenario. It must implement all policies and measures as framed under the 2 °C target scenario and still resort to capping oil consumption as one of the major pillars for achieveing the "Beautiful China" vision and all the ecological and environmental quality targets. This will ensure that oil consumption, after reaching its peak, will continuously decline and that by 2035, China's oil consumption will fall below 600 million metric tons, with oil making up 15.1% of primary energy consumption.

Between 2035 and 2050, China will center its efforts on the 2 °C and the 1.5 °C targets. Thanks to its previous energy transition efforts, China will stay on the fast track for low-carbon development. Its continuous policy efforts, relentless push for GHG emissions reductions, and adoption of CCUS technologies and carbon neutral solutions in oil and gas production will reduce oil consumption below 420 million metric tons by 2050, with oil accounting for 11.3% of primary energy consumption. This will ensure the fulfillment of the 2 °C target while improving the chances of achieving the 1.5 °C target. Table 4.1 shows the comparison of oil consumption under the above-mentioned oil cap pathway and under the baseline scenario. By 2025, oil consumption under the oil cap pathway will be reduced by 20 million metric tons relative to baseline levels; by 2050, by 350 million metric tons.

Given its highly imbalanced oil consumption between urban and rural areas and between different regions, China should first push for peak oil—in its eastern developed areas to create room for reasonable oil consumption growth in western, underdeveloped areas, as well as in the transportation sector to create room for oil demand growth driven by the petrochemical sector's use of petroleum as a feedstock to produce advanced products.

TABLE 4.1: OIL CONSUMPTION UNDER THE BASELINE SCENARIO AND UNDER THE OIL CAP PATHWAY FROM 2025 TO 2050

UNIT: MILLION TONS	2025	2030	2035	2040	2045	2050
Baseline scenario	740	770	776	780	777	770
Oil cap pathway	720	660	600	540	480	420
Reduction in oil consumption	20	110	176	240	297	350

TABLE 4.2: TOTAL ENERGY CONSUMPTION, OIL CONSUMPTION, PRIMARY ENERGY MIX AND CARBON EMISSIONS UNDER THE OIL CAP PATHWAY

	2018	2025	2035	2050
Total energy consumption (million tons of coal equivalent)	4,640	5,300	5,700	5,300
Oil demand (million tons of coal equivalent)	880	1,030	860	600
Oil (%)	18.9	19.4	15.1	11.3
Coal (%)	59	46.9	24.6	9.4
Natural gas	7.8	13	14	15.4
Non-fossil fuels (%)	14.3	20.7	46.3	63.9
Carbon emissions (billion tons of CO_2 equivalent)	9.9	10.1	6.9	4.0

2. PRIMARY ENERGY DEMAND AND CARBON EMISSIONS UNDER THE OIL CAP PATHWAY

Table 4.2 shows that China's total energy consumption will peak around 5.7 billion tons of coal equivalent by 2035. Under the oil cap pathway, when oil consumption peaks in 2025, oil will account for 19.4% of total energy consumption; in 2035, this figure drops to 15.1%; and in 2050, to 11.3%.

The oil cap pathway is an effective solution for adjusting the energy mix. In 2018, China consumed a total of 4.64 billion tons of coal equivalent, with coal, oil, natural gas and non-fossil fuels respectively accounting for 59%, 18.9%, 7.8% and 14.3%. By 2025, China's total energy consumption will amount to 5.3 billion tons of coal equivalent, with oil, coal, natural gas and non-fossil fuels respectively accounting for 19.4%, 45.9%, 13% and 21.7%. By 2050, its total energy consumption will return to 5.3 billion tons of coal equivalent, with oil, coal, natural gas and renewable energy sources respectively making up 11.3%, 9.4%, 15.4% and 63.9%. China's total energy consumption will decline continuously after reaching a peak in 2035. At the same time, the shares of coal and oil will shrink continuously in China's total energy consumption. Its energy mix will have a significantly increased weight of low-carbon and clean energy sources, along with a continuously expanding share of renewable energy, see Table 4.2.

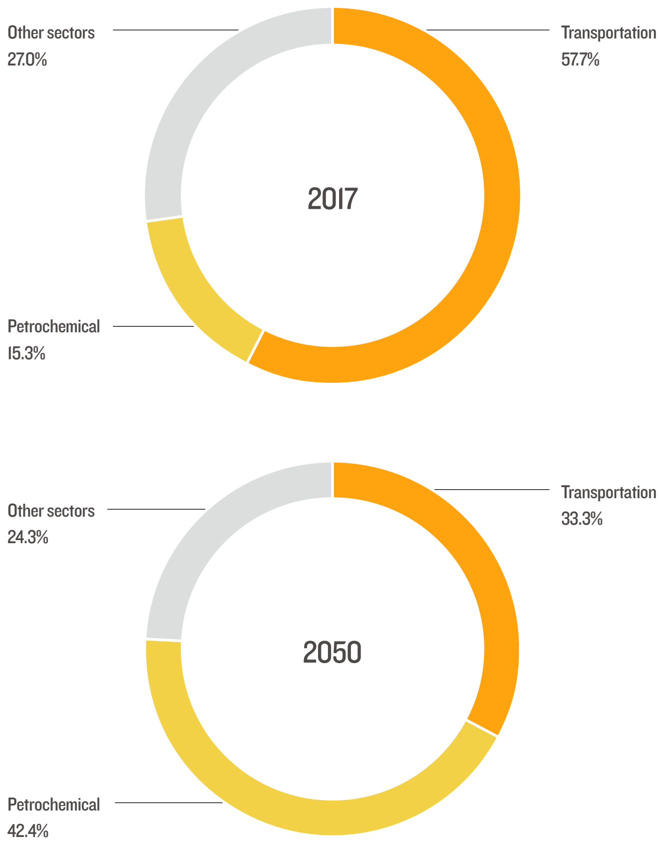
Under the oil cap pathway, oil only represents 19.4% of China's primary energy consumption at the time of peak oil, much lower than the percentage in developed countries, which stands around 40%. Therefore, China needs to accelerate its energy transition and advance the development of alternative energy sources.

China has set mandatory coal and non-fossil fuel cap targets as well as targets for energy efficiency, carbon intensity and coal used for power generation. In China's coal cap plan, 2013 was the peak year for coal consumption. However, between 2013 and 2018, the drop in carbon emissions as a result of reduced coal consumption was quickly offset by carbon emissions from increased oil and natural gas production and consumption.

The oil cap pathway, when combined with China's coal cap plan, will bring forward a carbon emissions peak around 2025. Table 4.2 shows that carbon emissions will reach its highest in 2025, amounting to 10.1 billion tons of the CO_2 equivalent. Thereafter, carbon emissions from oil and coal use will fall continuously thanks to the combination of the coal and oil cap pathways.

Interestingly, carbon emissions from natural gas consumption will be an issue to be reckoned with beyond 2050. We believe that beyond 2035-2040, China should re-orientate its position on the role of natural gas in resource use. If half of the natural gas is used as petrochemical feedstock by 2050, China will be able to reduce carbon emission by 500 million tons. When these efforts are combined with carbon sinks, the use of CCUS technologies and biomass power generation, China will stand a chance of solving another 3 billion tons of carbon emissions and achieving its carbon-neutral goal by the middle of this century.

FIGURE 4.2: PERCENTAGE OF OIL CONSUMED BY THE TRANSPORTATION, PETROCHEMICAL AND OTHER SECTORS IN 2017 AND 2050



3. IMPLEMENTATION ROADMAP FOR THE OIL CAP PATHWAY

One important safeguard for fulfilling targets under the oil cap pathway is developing actionable, measurable and verifiable plans and roadmaps and identifying key areas and main pillars.

3.1 Phased goals and target reductions under the oil cap pathway

There are three milestones for China's oil cap pathway: 1) peaking oil consumption at 720 million metric tons by 2025; 2) fulfilling the "Beautiful China" vision by 2035; and 3) achieving the 1.5°C target by 2050.

China consumed 589 million metric tons of oil in 2017, 57.7% of which was used by the transportation sector; 15.3% by the petrochemical sector; and 27.0% by other sectors. Under the oil cap pathway, China will consume 420 million metric tons of oil in 2050 and the amount of oil consumed by the above-mentioned three sectors will be respectively 140 million metric tons (33.3%), 178 million metric tons (42.4%) and 102 million metric tons (24.3%) (see Figure 4.2).

By 2050, China's oil consumption will be 350 million metric tons less under the oil cap pathway than under the baseline scenario, with the transportation, petrochemical and other sectors respectively decreasing 232, 50 and 68 million metric tons, each contributing 66.3%, 14.3% and 19.4% to the reduction. Between 2020 and 2050, China's cumulative oil consumption will be 5.34 billion metric tons less under the oil cap pathway than under the baseline scenario, an amount nine times as much as China's total oil consumption throughout 2017.

TABLE 4.3: DEFINITIONS OF THE FIVE APPROACHES UNDER THE OIL CAP PATHWAY

APPROACH	DEFINITION
Demand reduction	Reduce unncesseary oil demand by adjusting economic and industrial structure and improving planning, management and consumption patterns.
Efficiency improvement	Improve the efficiency of equipment and oil-consuming facilities through technology upgrades and phase out outdated oil-consuming equipment.
Replacement	Replace oil with other energy sources and alternatives.
Structural optimization	Optimize the structure of imports, exports, product portfolios and manufacturing processes and phase out outdated capacities, etc.
Clean use	Produce oil products according to clean production and environmental protection standards and reduce the amount of oil used for pollutants treatment.

TABLE 4.4: THE FIVE OIL CAP APPROACHES AND THE REDUCTIONS TO BE ACHIEVED

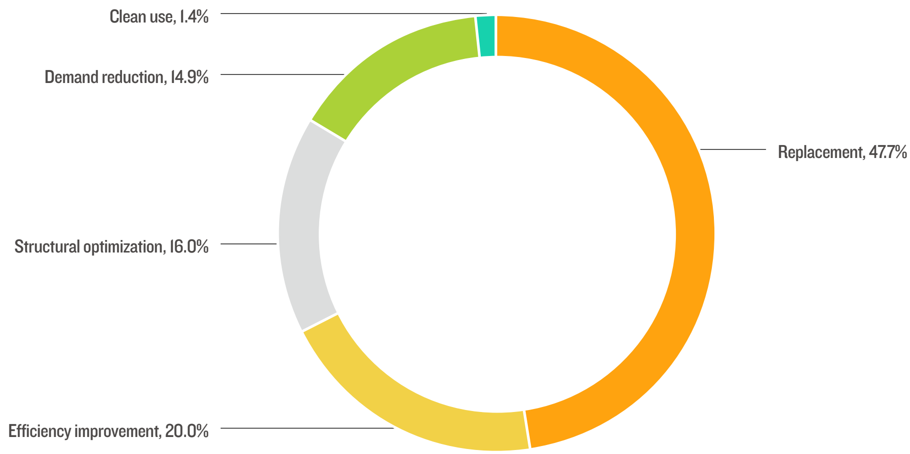
UNIT: MILLION TONS	TRANSPORTATION	PETROCHEMICALS	OTHER SECTORS	TOTAL
Reduction in 2050	232	50	68	350
Demand reduction	• reduce inefficient freight transport needs • develop compact cities and city clusters	• reduce the export of energy- and oil-intensive products • control the export of chemical products • import petroleum intermediates as substitutes for crude oil • restrict and ban the production and use of common plastics • improve recycling of chemical products	• reduce oil consumption from industry, construction and agriculture	52
Efficiency improvement	• improve vehicle fuel economy	• improve resource and energy efficiency	• improve oil efficiency standards to reduce loss and waste	70
Replacement	• develop electric vehicles and electrified transportation • develop alternative fuels such as fuel cells	• replace petroleum-based plastics with degradable materials • diversify raw materials and manufacturing processes	• replace ICE vehicles with electric vehicles	167
Structural optimization	• optimize passenger and freight transport structures • optimize urban transportation planning and the structure of intra-city transit modes	• diversify the sources of products supply • integrate refining and petrochemicals production to eliminate outdated capacities	• phase out outdated products	56
Clean use	• Improve the quality of oil products	• lift environmental protection standards for the petrochemical sectors • reduce petrochemical wastes through recycling	• use clean fuels	5

3.2 Five approaches to an oil consumption cap and their contribution rates

Measures taken by different sectors to control oil consumption can be summarized as five different approaches—reducing demand, improving efficiency, replacing oil with alternatives, optimizing industry structure and portfolios and encouraging clean use. Table 4.3 provides a definition for each of these five approaches. It's noted that these approaches are not completely independent of each other and may overlap in certain aspects.

In addition to the five approaches adopted by the three sectors, China should also strengthen its oil cap efforts by implementing policy, technological, managerial and investment measures. As shown in Table 4.4 and Figure 4.3, the contribution rate of these five major approaches to the total oil reduction of 350 million tons in 2050 is 14.9% from demand reduction, 20.0% from efficiency improvement, 47.7% from substitution, and

FIGURE 4.3: THE FIVE APPROACHES' RATES OF CONTRIBUTION TO THE 350 MILLION TON REDUCTION IN 2050



16.0% from structural optimization and 1.4% by clean use. Obviously, the importance of these approaches varies from sector to sector, but replacement and efficiency improvement contribute to a combined 67.7% of the reduction.

It is noted that the effect of a particular approach may be affected by factors such as the efficacy of policy implementation, technological progress and managerial expertise. We do not rule out the possibility that certain approaches may produce weaker- or strong-than-expected effects in reducing oil consumption.

3.3 Priority of sectors for an oil consumption cap and their focuses

Based on sectoral contribution rates and difficulties, China should assign priority in the order of transportation, petrochemical and other sectors in capping oil consumption. Among the major oil-consuming sectors, each sector can drive oil cap efforts by resorting to measures that are the most actionable and instrumental in capping oil consumption and reducing energy use and carbon emissions.

The transportation sector should focus on banning traditional petrol and diesel vehicles, replacing traditional fuels with electricity, biofuels, natural gas and hydrogen energy and promoting NEVs. It should aim to develop a green, low-carbon transportation system based on electricity and dominated by rail transport and public transport service. The transportation sector will be the first to achieve peak oil between 2020 and 2025. Banning traditional vehicles will contribute to 65% of the sector's oil reduction by 2050, while helping address the chronic urban air pollution issues and reducing carbon emissions.

Figure 4.4 provides an outlook on the transportation sector's oil consumption. Under the baseline scenario, the sector's oil consumption will peak and plateau around 390 million metric tons during 2035-2040. Under the oil cap pathway, the transportation sector's oil consumption will begin to slow down and reach a peak between 2020 and 2025—thanks to the increasing substitution of electric vehicles for traditional ICE vehicles, improved fuel economy and optimized transportation structure. Between 2025 and 2035, the growing maturity of technology and infrastructure for vehicle electrification will result in an explosive growth of electric vehicles. This eletrification trend, combined with innovative IT-based business models such as shared transportation and connected logistics, will further reduce transportation needs and cause a rapid decline in oil consumption in the transportation sector. Between 2035 and 2050, the sector's oil consumption will continue to go down, but at a slower rate. During this period, the electrification of passenger and commercial vehicles will slow down, but alternative fuels for medium- and heavy-duty trucks as well as for water and air transportation will gradually become mature, further driving down oil consumption in the transportation sector. By 2050, the sector's oil consumption will drop to 140 million metric tons, 232 million metric tons less than under the baseline scenario.

The petrochemical sector should focus on the restriction and clean use of plastics. In 2018, China used 80 million metric tons of petroleum for plastics production. Plastics have not only caused great harm to land and marine ecosystems, but also represent a serious health threat to the general public. Prohibiting and restricting plastics has become a global trend. Reducing, replacing and recycling plastics can reduce the sector's oil consumption by 19 million metric tons, or 38% of the sector's oil cap target for 2050.

Figure 4.5 provides an outlook for oil demand in the petrochemical sector. Under the baseline scenario, the fast-growing production of petrochemical products will continuously drive up petrochemical oil demand, which will

FIGURE 4.4: OUTLOOK FOR THE TRANSPORTATION SECTOR'S OIL DEMAND UNDER THE BASELINE SCENARIO AND THE OIL CAP PATHWAY

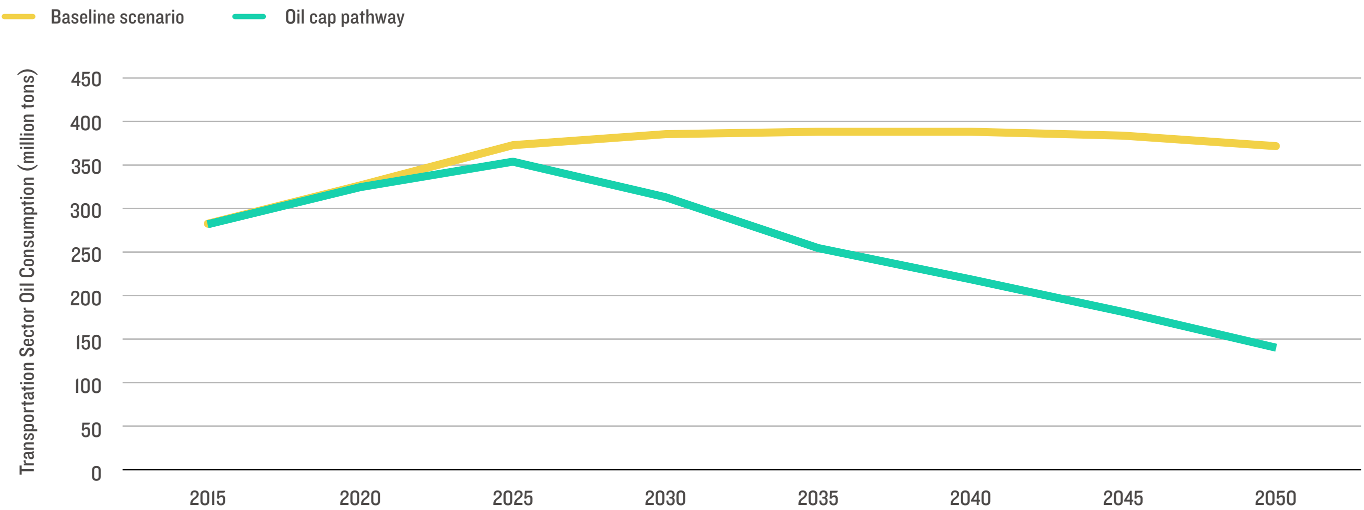
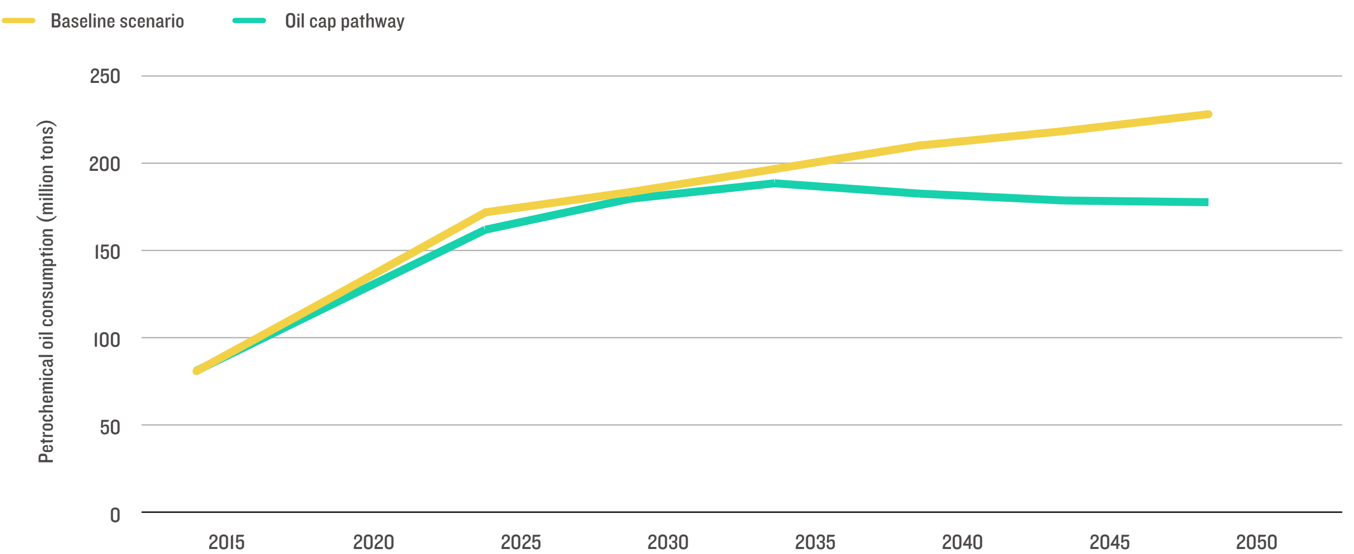


FIGURE 4.5: OUTLOOK FOR THE PETROCHEMICAL SECTOR'S OIL DEMAND UNDER THE BASELINE SCENARIO AND UNDER THE OIL CAP PATHWAY



grow at a fast speed during 2015-2030 and then at a steady pace. By 2050, the sector's oil demand will reach 191 million metric tons by 2050. Under the oil cap pathway, petrochemical oil consumption will continue to rise rapidly during 2015-2030, but its growth speed will be lower than under the baseline scenario thanks to measures such as the restriction of plastics, reduced export of petrochemical products, the phase-out of outdated capacities and improved energy efficiency. By 2035, the sector's oil consumption will reach a peak of 190 million metric tons, followed a gentle downward slope due to the combination of feedstock substitution and increased import of basic chemicals. By 2050, the sector is expected to cap its oil consumption at 178 million metric tons, 50 million metric tons less than under the baseline scenario.

Other sectors should give priority to imposing stricter standards, particularly new standards for energy efficiency for various types of diesel engines and pollutant emissions. Diesel engines are usually highly polluting and energy inefficient. Eliminating outdated gasoline and diesel engines (demand reduction) and improving energy efficiency and emission standards (efficiency improvement and clean use) will save 36 million metric tons of oil, or over 52% of the 2050 oil cap target of other sectors. As a whole, other sectors' oil consumption will peak between 2025 and 2030.

Overall, the three main measures of "banning traditional ICE vehicles", "restricting plastics" and "imposing stricter standards", could together contribute to 59% of the 350 million ton oil reduction target set out in the roadmap for 2050.

3.4 Priority regions for oil consumption control and differentiated regional oil cap strategies

Due to China's highly imbalanced development between urban and rural areas, the country is faced with the dilemma of growing oil consumption and the need to reasonably control oil use nationwide. Currently, per capita oil consumption in Shanghai, Tianjin and Liaoning has exceeded one metric ton, a level comparable to that of the UK and France. By contrast, this figure is only about 0.2 metric ton in Hebei, Shanxi, Henan and Shaanxi, a level that is about half of the national average (see Figure 4.6).

Given this geographical imbalance, developed cities in east and central China are expected to peak their oil consumption earlier than the rest of the country. They are also supposed to actively take measures to reduce total oil consumption. These developed cities as well as key areas/provincial capitals should also rigorously control car ownership growth and take the lead in introducing targets for the phase-out of traditional ICE vehicles as well as developing actionable roadmaps. They should speed up their pace to eliminate the outdated refining capacity of petrochemical companies and also take the lead to define targets and roadmaps for completely banning single-use plastic products. While some western developed regions may lag behind the rest of the country in terms of peaking oil consumption, they should also develop oil cap targets and policies to strictly control oil consumption growth and push for peak oil. China should implement pilot projects in different areas and learn from best practices, which can be extended nationwide as part of its effort to develop a national oil cap roadmap and timetable.

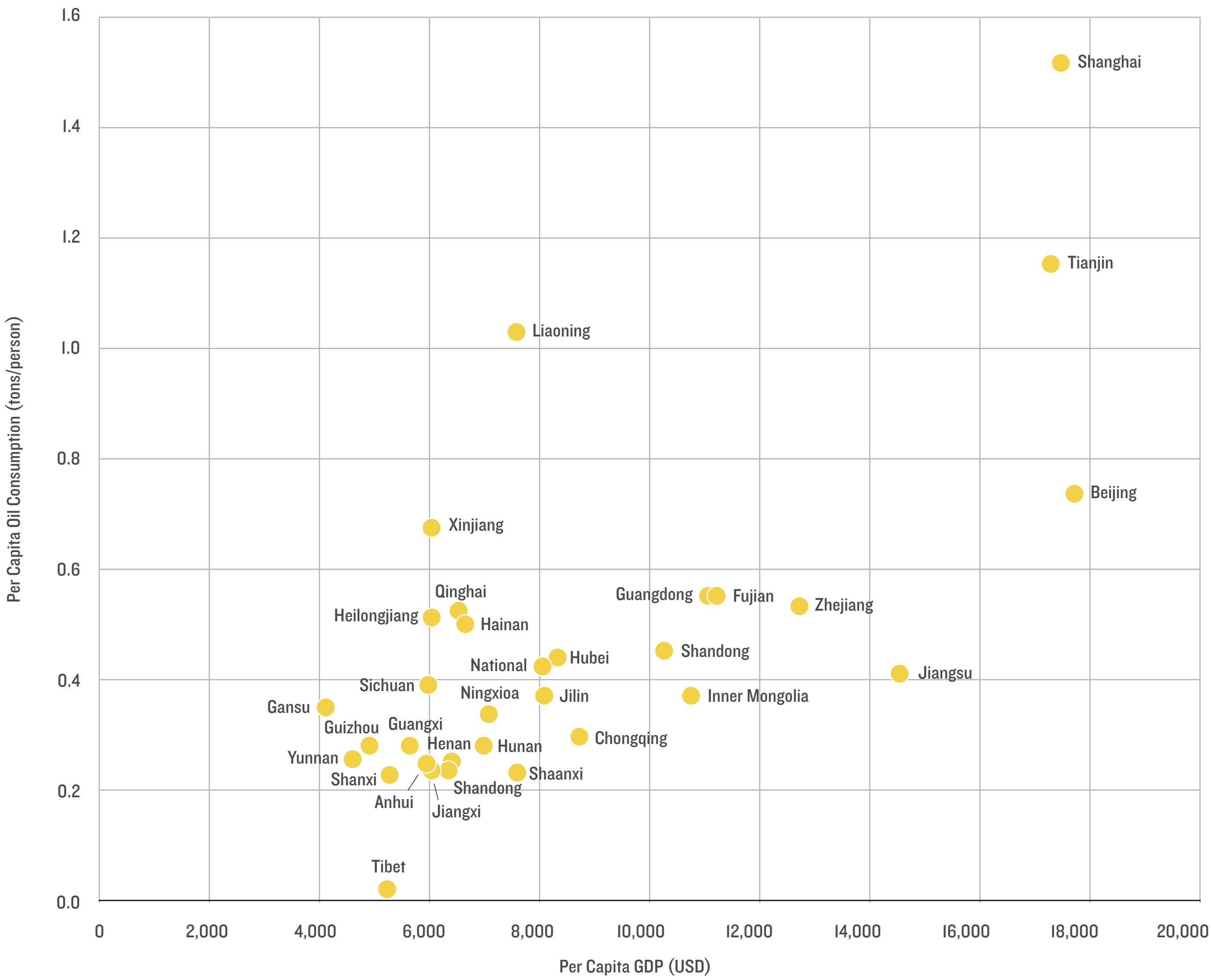
3.5 Establishing an indicator system for oil consumption control

Focusing on the central issue of achieving the oil cap target, China is advised to develop an oil cap indicator system that reflects its needs in for an energy transition, environmental protection, climate change and core decision-making, and incorporate this indicator system in its short-, medium- and long-term development plans (such as its five-year, fifteen-year and 2050 plans).

China's existing energy indicator system is composed of national and sectoral targets, some of which are mandatory and others guiding. Important national macro indicators can be broken down to localities and sectors when necessary. Annex 2 introduces China's existing national energy indicators. Under the oil cap pathway, China may select a group of indicators to guide and curb oil consumption (see Table 4.5).

Indicators can be divided into guiding, early warning and mandatory indictors. This report recommends three national macro indicators and three sectoral indicators. Among the three national indicators, the share of oil in primary energy consumption is a guiding indicator, the dependence on crude oil imports is an early warning indicator, and the "dual-credit"

FIGURE 4.6: PER CAPITA OIL CONSUMPTION VS. PER CAPITA GDP BY PROVINCE



Source: China Energy Statistical Yearbook 2018, China Statistics Press, May 2019

TABLE 4.5: OIL CAP INDICATOR SYSTEM UNDER THE OIL CAP PATHWAY

	IMPORTANT INDICATORS	2025	2035	2050	SUGGESTED REQUIREMENT
National macro indicators	Share of oil in primary energy consumption (%)	19.4	15.1	11.3	Guiding
	Import oil dependence (%)	72	67	48	Early warning
	Energy efficiency	"Dual-credit" scheme	"Dual-credit" scheme	-	Mandatory
Sectoral indicators	Banning traditional ICE vehicles	Timetables for the ban of traditional diesel and petrol vehicles in pilot provinces and cities	Differentiated local timetables for the ban of traditional diesel and petrol vehicles	Phasing out traditional diesel and petrol vehicles nationwide	Mandatory
	Petrochemical	Plastics restriction+recycle	Plastics restriction+recycle+replacement	Complete ban of plastics	Mandatory
	Other sectors	Raise Gasoline and diesel engine energy efficiency and emission standards	Raise Gasoline and diesel engine energy efficiency and emission standards	Raise Gasoline and diesel engine energy efficiency and emission standards	Mandatory

scheme for passenger cars' fuel efficiency and NEVs should be raised to a nationally mandatory indicator.

In the 14th Five-Year Plan, China could respectively reduce the percentage of oil in primary energy consumption below 19.5% and import oil dependence below 73% by 2025; below 15.2% and 67% by 2035; and below 11.4% and 52% by 2050.

From the perspective of safeguarding and enhancing energy security, oil consumption and external dependence indicators will help increase efficient use of oil and the development and utilization of alternative energy resources, and then gradually reduce dependence on imported oil. In the transportation, petrochemical and other sectors, phasing out ICE vehicles, restricting plastics, and setting energy and emission standards for gasoline-diesel engines are recommended as sectoral binding targets. Banning ICE vehicles and the restricting plastics should be upgraded from local targets to national targets.

4. AN OIL CAP CAN PROMOTE ECONOMIC DEVELOPMENT

The purpose of a total oil consumption cap is to encourage China to leap over the Age of Oil, positively impacting the environment, public health and climate change and reducing the external environmental costs for the whole of society. In the transportation sector, this means promoting an automobile revolution and fostering the development of emerging industries. In the petrochemical sector and other industries, promoting R&D and the industrialization of energy-efficient, environmentally sensitive technologies is recommended. In addition, we recommend encouraging the substitution of oil-based plastics by other innovative materials and furthering the development of technologically innovative industries. In the oil and gas exploration sector, promoting the technological revolution of shale oil and gas extraction is of vital importance. The above stated recommendations could drive economic growth.

4.1 Reducing the external environmental costs on society

In 2015, the external cost on society generated by China's oil exploitation and utilization was 275.5 billion RMB. Because of the rising negative effects on public health and the environment, as well as the increasing risk of climate change, it is expected that the total external costs in 2025, 2035 and 2050 will reach 510 billion RMB, 580 billion RMB and 1,120 billion RMB respectively. The implementation of the oil consumption cap plan can reduce these costs significantly by 20.4 billion RMB, 128 billion RMB and 509 billion RMB in 2025, 2035 and 2050 respectively.

4.2 Nurturing the automobile revolution and developing emerging industries

The automobile sector is one of the pillar industries for China's economic growth. In 2017, the secondary industry contributed 2.5% to GDP growth; the automobile industry contributed 7% to total GDP, representing the largest contribution, and the profit of the traditional automobile industry accounted for 9.2% of the total industry profit. The production and sales of traditional ICE vehicles has started to decline since 2018 in China, and NEVs have gone against the trend and became a new growth polar for the automobile industry. The development of electric vehicles has led to the rise of the entire industrial chain such as batteries and other parts, which has also had a huge positive impact on the power industry and the development of renewable energy. Other ancillary services, such as power distribution services and charging points, have also developed rapidly. The electrification of the transportation sector will bring about tremendous changes to existing transportation systems (including road traffic, shipping and aviation) and energy systems. It will also bring about leapfrog development to China's transportation, manufacturing, energy and service industries.

4.3 The demand for energy efficient, low-carbon technology and a revolution in unconventional oil and gas exploitation will promote the rise of technologically innovative industries

In various sectors, processes and terminal equipment, new energy efficienty and environmentally friendly technologies and equipments should be developed and promoted in order to reduce the oil consumption, pollutants and carbon emissions. From the production side, the development of unconventional oil and gas resources has brought revolutionary progress in the field of oil exploration. New developments and reforms will follow in terms of technology, equipment, management and investment. The impact of the unconventional oil and gas revolution is far-reaching. Some new businesses and industries showed great potential during the development of CO_2 enhanced oil recovery (EOR), which is the most practical and promising technology among the current CCUS technology options.

5

OIL CAP PATHWAYS IN THE TRANSPORTATION SECTOR

The Third Industrial Revolution remains in full swing worldwide. Continuous innovation and development of NEVs, car sharing, driverless vehicles, intelligent transportation and the Internet of Things has created opportunities that will make peak oil in the transportation sector possible. The highly efficient development of transportation infrastructure in China has created enormous room for the sector's structural optimization and upgrading. The rapid development of high-speed railway, air and water transportation, the demonstration, promotion and fast penetration of NEVs and the transportation transformation led by automobile revolution all present strategic opportunities for China to capitalize on its late-mover advantage and leap over the age of oil. In this context, we believe that China should push for peak oil in the transportation sector before 2025.

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OIL CONSUMPTION CHARACTERISTICS OF THE TRANSPORTATION SECTOR

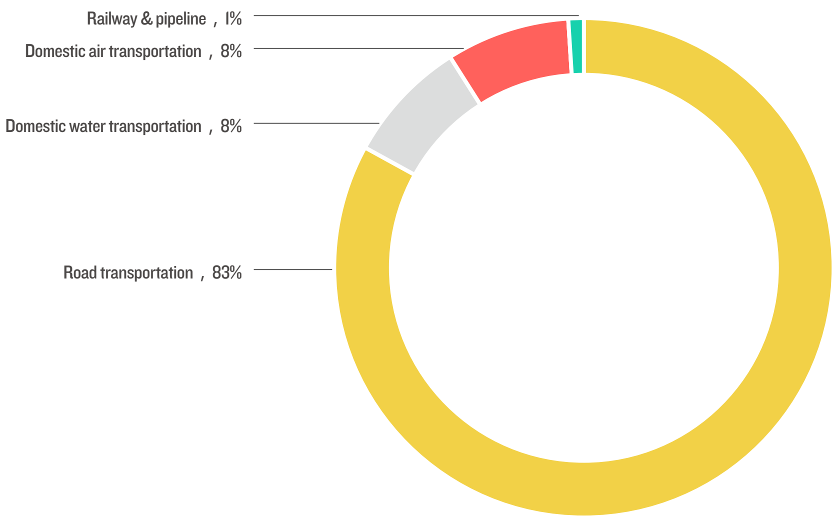
Figure 5.1 breaks down the transportation sector's oil use by road, railway, water, air and other transportation modes. Road transportation, as the largest consumer of oil, uses 83% of the transportation sector's total oil consumption, followed by water transportation (8%), air transportation (8%) and then railway and pipeline transportation (1% together). The trend shows that oil consumption by air transportation is growing faster than other segments, which means that the share of oil used by road transportation will be increasingly reduced making room for air transportation.

Railway transportation is mainly powered by electricity, which makes up 95% of its total energy consumption, with diesel accounting for the remaining 5%. Road transportation is still predominantly fueled by oil. In terms of energy intensity, water transportation is the lowest, standing at 2.7 metric tons of coal equivalent/million ton-km; railway transportation is the second, at 4.8 metric tons of coal equivalent/million ton-km; road transportation is the third, at 18 metric tons of coal equivalent/million ton-km; and air transportation is last[22]. Therefore, railways are much more energy efficient than roads when transporting commodity goods and passengers over long distances, and a transition from road to railway and water transportation will reduce energy consumption and air pollution.

Figure 5.2 shows the amount of various fuels consumed from 2006 to 2017. In 2017, China consumed a total of 327 million metric tons of fuels, up 3.4% from last year. Among them, gasoline consumption stood at 124 million metric tons, up 4.6%

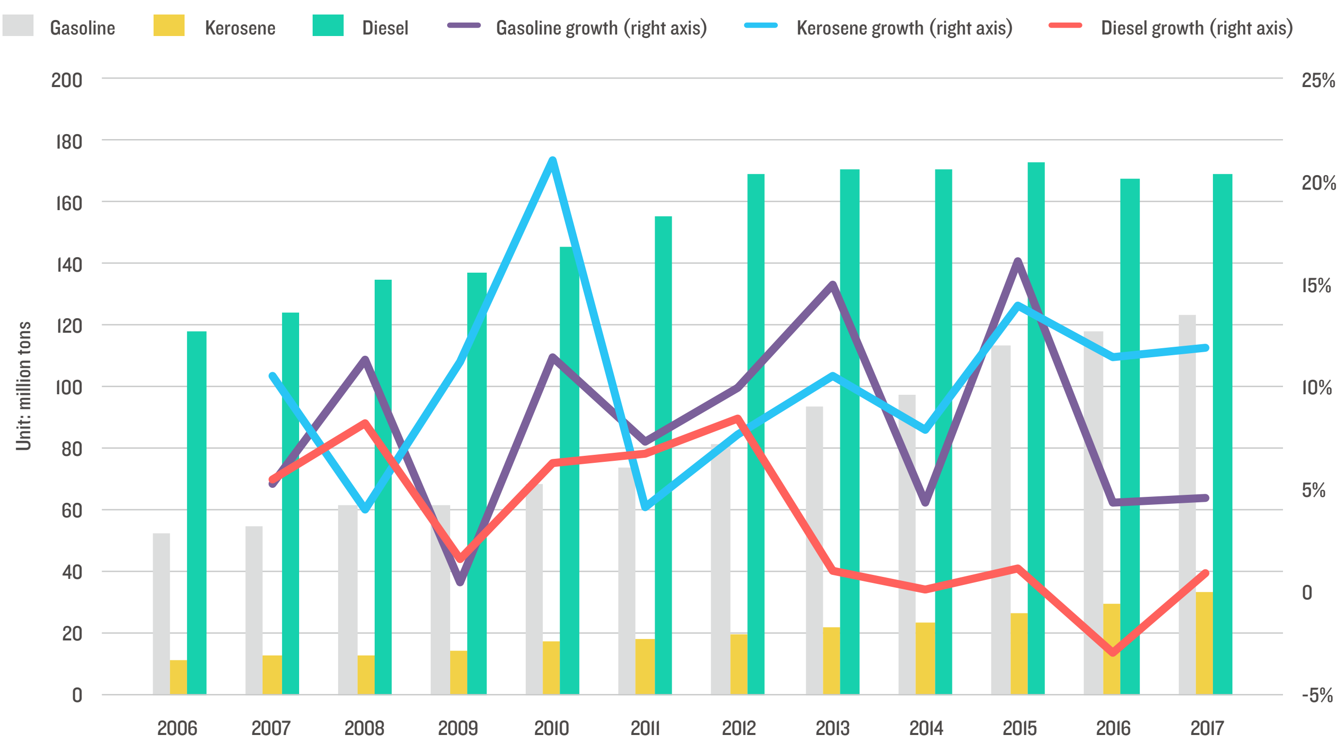
[22] A Strategic Study on Promoting Energy Production and Consumption Revolution (Phase I), Chinese Academy of Engineering, June 2017

FIGURE 5.1: BREAKDOWN OF TRANSPORTATION SECTOR OIL CONSUMPTION IN 2017



Source: *China Energy Statistical Yearbook 2018*, Energy Department, National Bureau of Statistics; June 2019
China Energy Flow Chart and Oil Flow Chart, Hu Xiulian and Liu Jia, China Oil Consumption Cap Plan and Policy Research Project, June 2019

FIGURE 5.2: GASOLINE, DIESEL AND KEROSENE CONSUMPTION IN CHINA



Source: 2006-2016 data of the National Bureau of Statistics; 2017 data of Wind Database from last year and diesel consumption was 170 million metric tons, up 0.9% from last year. The rapid development of the aviation sector has led to rapid growth in kerosene demand. In 2017, China consumed a total of 33.26 million metric tons of kerosene, up 12% from last year. The growth of kerosene consumption has also been the fastest among the three major fuels, with an average annual growth rate of over 10% between 2006 and 2017.

Diesel is mostly used by trucks, large passenger vehicles and ships. Apart from the transportation sector, non-road mobile machinery are also important oil users, and are usually highly polluting and energy inefficient. They are also a major source of urban air pollution, even causing more pollution than motor vehicles in some cities.

1. THE TRANSPORTATION SECTOR'S OIL REDUCTION POTENTIAL AND POLICY OPTIONS UNDER THE OIL CAP PATHWAY

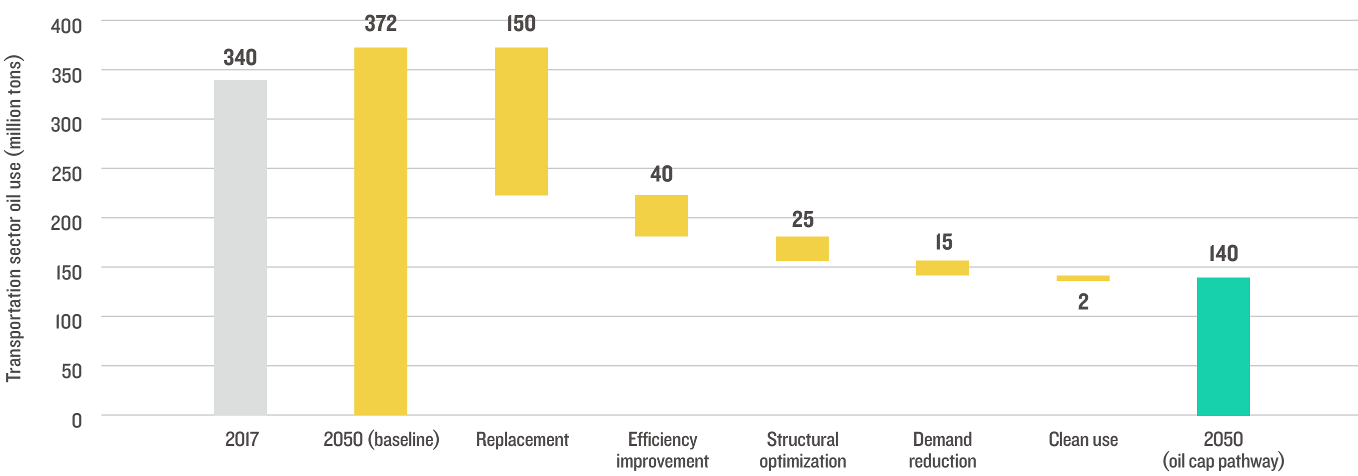
Overall, oil consumption in transportation sector will peak earlier than in petrochemical and other sectors. In view of their current levels of consumption and future trends, different fuels will reach peaks at different times, but road transportation is an undisputed priority segment for oil cap given its total energy use as well as its share in total oil consumption.

Under the oil cap pathway, the transportation sector will use 140 million metric tons of oil by 2050, 232 million metric tons less than under the baseline scenario. As shown in Figure 5.3, China can reduce oil consumption by 150 million metric tons (64.6%) through encouraging the use of NEVs, by 40 million metric tons (17.2%) through improving fuel economy, by 25 million metric tons (10.8%) through optimizing transportation structure by using railway and water modes for freight transportation and more efficient intra-city transite modes, by 15 million metric tons (6.5%) through changing development and travel patterns and reducing inefficient transportation demand, and by 2 million metric tons (0.9%) through clean use.

It should be noted that potential oil reductions under these oil cap approaches are calculated based on China's short- and medium-term policy environment and technological foundation. However, we do not rule out the possibility that more ambitious reduction targets may be accomplished in one way or another, but this will depend on various factors such as political will, policy options, technology innovation and application, investment and financial support, and pollutant and carbon emissions reduction.

Oil demand reduction and electrification is a long-term trend for the transportation sector, but it cannot be achieved overnight. China needs to coordinate the five approaches—demand reduction, efficiency improvement, replacement,

FIGURE 5.3: OIL REDUCTION POTENTIAL AND APPROACHES IN THE TRANSPORTATION SECTOR BY 2050



structural optimization and clean use—on both the supply and demand sides from short-, medium- and long-term perspectives. In the short term, China should continue to improve fuel economy standards for traditional ICE vehicles; accelerate the development of transportation infrastructure dominated by high-speed railway and public transportation modes, with a focus on the structural adjustments; and enhance planning for industrialization and urbanization to solidify the foundation for medium- and long-term structural optimization. At the same time, China can speed up the R&D, demonstration and promotion of vehicles powered by electricity and fuel cells as well as of alternative fuels, so as to ensure that electrification potential will be fully unlocked in the medium and long term.

TABLE 5.1: SELECTED POLICY OPTIONS AND MEASURES FOR CAPPING TRANSPORTATION SECTOR OIL CONSUMPTION

APPROACH	KEY AREAS	EVALUATION INDICATORS	POLICY OPTIONS AND MEASURES
Demand reduction	Reduce inefficient freight transportation needs	• Freight transport intensity • Empty-loaded rate	1. Accelerate the adjustment of economic and export structures and develop advanced manufacturing and the tertiary sector 2. Improve the planning of industries to reduce long-distance transportation 3. Optimize logistical organization through Information and Communication Technologies (ICT)
	Develop compact cities and city clusters	• Urban road density • Times & percentage of motorized travels	4. Guide mixed-functional zoning and multi-function clustering in big, medium-sized and small cities 5. Increase urban road densities
	Economic measures	• Raise oil prices	6. Raise fuel tax to internalize external cost
Efficiency improvement	Improve vehicle fuel economy	• Truck fuel economy • Passenger car fuel economy • Commercial vehicle fuel economy	7. Significantly improve fuel economy for passenger and commercial vehicles and enhance the energy efficiency leader system 8. Implement different tax policies for vehicles with different levels of energy efficiency
Replacement	Develop NEVs	• Penetration rate of electric vehicles (EVs) • Percentage of travels by EV	9. Raise the targets and requirements of the "dual-credit" scheme 10. Improve subsidy and tax policies for EVs 11. Accelerate the development of charging infrastructure 12. Speed up the R&D, demonstration and promotion of vehicles powered by hydrogen energy and fuel cells 13. Research and release the timetable for the phase-out of traditional ICE vehicles
	Develop alternative fuels	• Percentage of natural gas-powered vehicles and ships • Utilization scale of biofuels	14. Accelerate the development of filling facilities for natural gas-powered vehicles and ships 15. Establish an appropriate natural gas pricing system to improve economic incentives 16. Provide policy support for the R&D and promotion of biofuels
Structural optimization	Optimize the structure of freight transportation	• Share of freight transported by railway • Share of intermodal transportation	17. Deepen the reform of the railway market to make railway freight transportation more competitive 18. Speed up the development of logistics hubs and platforms 19. Support the development of intermodal transportation
	Optimize the structure of urban transportation	• Share of non-motorized travels • Share of travels by public transportation • Share of travels by shared transportation	20. Make public transportation more comfortable and convenient 21. Improve transfer facilities for public transportation services and railway systems 22. Build non-motorized infrastructures including bike travel facilities 23. Enhance parking and congestion pricing policies 24. Strengthen policy support for shared transportation
Clean use	Improve the clean use of fuels	• Emission standard for pollutants from motor vehicles, such as nitrogen oxides • Fuel oil quality standard • Clean design and production	25. Designate low emission zones 26. Strengthen the control of old and outdated diesel vehicles 27. Study and release urban congestion pricing regulations 28. Change production process to lower cost and improve oil product quality 29. Minimize waste discharge and treatment

Specifically, we will explore the oil-saving potential of the transportation sector, specify various technologies and models for the five major approaches, and issue policy recommendations for key areas (see Table 5.1). However, given the fact that a transportation sector energy transition involves many other sectors and areas and that the level of industrialization and urbanization varies significantly from place to place, these measures will involve holistic coordination, different challenges and varying paces of implementation.

2. SPECIFIC MEASURES FOR THE TRANSPORTATION SECTOR UNDER THE FIVE APPROACHES

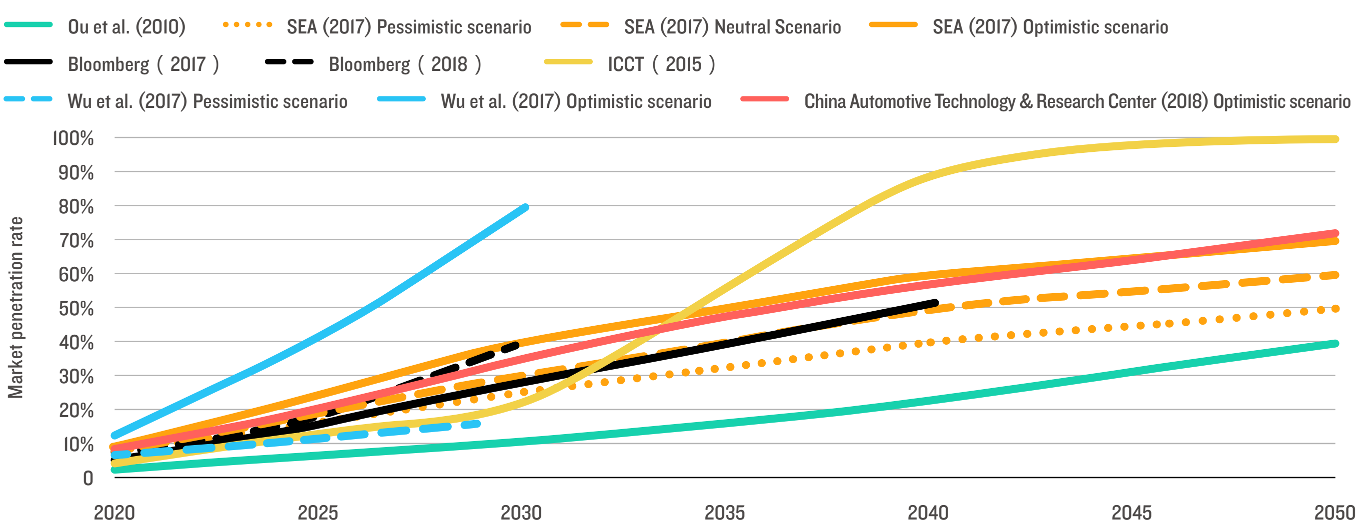
2.1 Reduce oil consumption by 150 million metric tons through accelerating NEV development oil substitutions

Currently, China is the world's largest maker and seller of automobiles. In 2018, there were 232.3 million civilian vehicles in China. Among them, there were 2.61 million NEVs (1.09%), an increase of 1.07 million, or 70%, from 2017. Of the 2.61 million NEVs, 2.11 million were battery electric vehicles (BEVs), making up 81.06% of the total[23]. In cities, more than 50% of public transportation vehicles have been electrified[24]. In cities such as Shenzhen and Taiyuan, taxis are already 100% electrified.

China is already at the forefront of electric vehicle industrialization, driven by constant technological breakthroughs and business model innovations. The EV market, which was previously solely pushed by government policy, is now increasingly characterized by two growth drivers—government guidance and market participants. In this context, if China can adjust fiscal subsidies and policy incentives in a timely manner, accelerate the development of infrastructure such as charging stations, introduce right-of-way and other supporting policies, and accelerate battery technology R&D, then some developed regions and cities in China will take the global lead in entering an "NEV society".

Different institutions have produced various scenario-based projections regarding the future of NEVs. Despite their varying preconditions and constraints, their projections as a whole point to an upward trend. Even conservative projections show that the penetration rate of NEVs will exceed 40% by 2050 (see Figure 5.4).

FIGURE 5.4: FORECASTS FOR NEV PENETRATION GROWTH

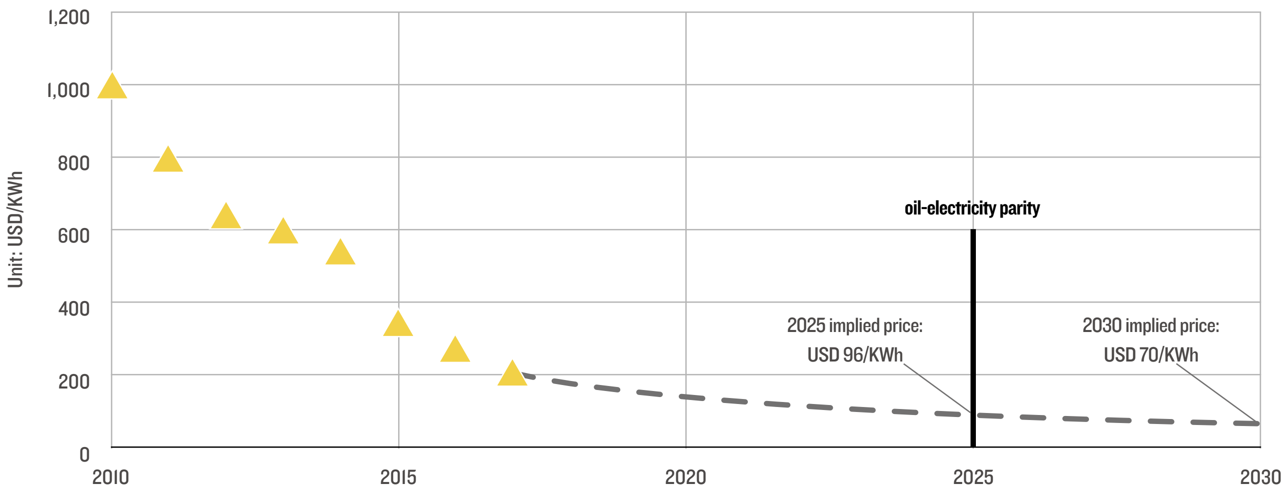


Source：A Study on China's Timetable for Phasing Out Traditional ICE-Vehicles, Innovation Center for Energy and Transportation (iCET), China Oil Consumption Cap Plan and Policy Research Project, May 2019

[23] Data from the Ministry of Public Security, January 2019

[24] 2018 Research Report on the Promotion and Use of New Energy Public Buses in China, Laboratory of Advanced Public Transportation Science, June 2019

FIGURE 5.5: THE DOWNWARD CURVE OF BATTERY PRICES (2010-2030)



Source: New Energy Outlook 2018, Bloomberg New Energy Finance, June 2018

According to research by Bloomberg New Energy Finance (BNEF), lithium battery pack price will fall to USD 96/KWh by 2025, when EVs and ICE vehicles reach price parity (see Figure 5.5). With power battery prices falling continuously, China is expected to take EVs from an early demonstration stage into a fast-growing stage of quick adoption before 2030.

In 2018, China produced 27.809 million and sold 28.081 million traditional ICE vehicles, continuing their 2017 decline and respectively falling 4.2% and 2.8%. By contrast, the production and sales of NEVs maintained strong momentum, growing respectively 59.9% and 61.7% in 2018[25]. Currently, China owns 45% of the world's total NEVs[26]. After the Chinese government scaled back subsidies, in the first six months of 2019 NEV market growth slowed, but still expanded by 70%. In July 2019, monthly sales of NEVs declined for the first time, by 4.7%[27]. Once NEV makers have adapted to the new subsidy policy, NEV sales are expected to reach a higher level.

Apart from conventional EVs, China has also seen rapid growth in various types of mini EVs, whose sales volume totaled 1.75 million units in 2017, more than 100% higher than that of conventional EVs. At present, there are more than 80 million motorcycles in China. By encouraging the use of electric motorcycles and mini EVs, China can not only dramatically reduce its fossil fuel demand but can also significantly improve the quality of its urban environments. Despite the fact that automobiles are quickly becoming a household necessity, China is expected to avoid the phenomenon of increasing motorcycle use that is common in cities in developing countries. Instead, China will create a different EV development path than that of developed economies.

In terms of transportation sector electrification, priority should be given to public buses, taxis, ride hailing vehicles, urban logistics vehicles and government vehicles. Electrification of these vehicles is the most feasible in terms of economics, technology commercialization and government promotion. To speed up the adoption of NEVs, the government should play a leading and exemplary role in purchasing NEVs. According to data roughly collected from Chinese government procurement websites, governments at various levels purchased a total of RMB 16 billion worth of vehicles in 2018[28]. In addition to providing policy support and encouraging a revolutionary transition in transportation, the government should also enhance the role of public procurement in supporting the development of advanced NEV companies. According to relevant government requirements, NEVs will make

[25] Data from the China Association of Automobile Manufacturers, January 2019

[26] Global EV Outlook 2019, International Energy Agency, May 2019

[27] Data from the China Association of Automobile Manufacturers, September 2019

[28] Ten Places Make Up Nearly 80% of Government Vehicle Purchases in 2018, Government Procurement Information, January 2019

up half of public buses in China by 2020. This timetable should also apply to Chinese government vehicles[29].

Apart from replacing oil with electricity, the use of natural gas in public buses, taxis, medium- and heavy-duty trucks also shows enormous potential. According to data from the International Association of Natural Gas Vehicles, there were already 6.08 million natural gas vehicles (NGVs) in China by the end of 2017, including 5.73 million compressed natural gas vehicles (CNGVs) and 350,000 liquefied natural gas vehicles (LNGVs). In terms of consumption, natural gas used by private vehicles was estimated at 7 billion cubic meters, accounting for about 20% of total vehicle natural gas use[30]. In 2017, NGVs consumed approximately 35 billion cubic meters of natural gas, about 50% of which was used by LNGVs, including heavy-duty trucks and large passenger vehicles[31]. Medium- and heavy-duty trucks are the ideal vehicles for the application of hydrogen fuel cells.

Moreover, biodiesel, ethanol and methanol gasoline and other liquid fuels are also alternative low-carbon energy sources. With policy efforts under the oil cap pathway, liquid biofuels are expected to substitute for 13 million metric tons of oil by 2030[32]. Globally, more than 40 countries and regions have introduced mandatory biofuel blending requirements. In 2017, the world produced a total of 84.12 million metric tons of liquid biofuels (including ethanol gasoline and biodiesel), a 5.3% increase from 2015. Many countries that are rich in biomass resources or are big grain producers have set forth liquid biofuel development as an important driver for expanding the production of renewable energy. For example, the US uses corn as the main feedstock for producing bioethanol fuel. In 2017, the US produced 36.93 million metric tons of liquid biofuels, accounting for 44% of the world's total. Brazil relies on sugar cane as the main feedstock for the integrated production of sugar and ethanol. As the world's second largest producer and consumer of bioethanol fuel, Brazil has extended the use of ethanol as a vehicle fuel nationwide[33].

As of 2017, China had produced 2,147,000 metric tons of liquid biofuels, only accounting for 2.6% of the world's total, and consumed about 3 million metric tons of liquid biofuels, less than 1% of the country's refined oil consumption. The National Energy Administration of China said in September 2017 that the use of ethanol fuel had been piloted in 11 provinces nationwide, including all the cities in the six provinces of Heilongjiang, Henan, Jilin, Liaoning, Anhui and Guangxi, and 31 cities in the five provinces of Hebei, Shandong, Jiangsu, Inner Mongolia and Hubei. At the time ethanol gasoline already made up one fifth of the national gasoline consumption[34]. In September 2017, the state also released the Implementation Plan for Expanding the Production of Bioethanol Fuel and Promoting the Use of Ethanol Fuel for Vehicles, which mandates a basic nationwide use of ethanol fuel by 2020.

China has much potential to unlock in terms of liquid biofuel development and utilization. Twenty million metric tons of bioethanol fuels could be produced if 30% of the over 400 million tons of straw and forest waste generated by China annually could be utilized. China could also go a step further to develop biodiesel by recycling waste cooking oil and food waste to produce non-edible vegetable oils and microalgae. After 10-plus years of development, China's "1.0 gen" and "1.5 gen" technology and processes that use feedstock such as corn and cassava to produce biofuels have become mature and stable; the "2.0 gen" technology that uses straw, agricultural and forest waste to produce biofuels is also ready for industrialization. Overall, China is already at the forefront of biofuel production technology and equipment. In the aviation field, China is also equipped with mature technology to produce quality biological aviation kerosene using palm oil and waste kitchen oil as the feedstock.

2.2 Reducing oil consumption by 40 million metric tons through significantly improved fuel economy for passenger cars and freight transportation vehicles

Traditional ICE vehicles also offer a huge source of energy savings. It is proven that one of the most effective and prevailing measures to reduce oil consumption for ICE vehicles is to

29 Measures for the Administration of Official Vehicles for Party and Government Organs, General Office of the CPC Central Committee, General Office of the State Council, December 2017

30 Data from the International Association of Natural Gas Vehicles, September 2018

31 China's Natural Gas Vehicle Ownership Ranked 1st Globally for 4 Consecutive Years, China Energy News, September 10, 2018

32 A Study on the Potential and Roadmap of Developing Biofuels as Oil Substitutes in China, Motion ECO, China Oil Consumption Cap Plan and Policy Research Project, June 2019

33 2018 Energy Data, Wang Qingyi, October 2018

34 National Energy Administration's Q&A regarding the Implementation Plan for Expanding the Production of Biofuel Ethanol and Promoting the Use of Ethanol Gasoline for Vehicles, September 2017

© Photo by Matthew T Rader on Unsplash

continuously lift fuel economy criteria for ICE vehicles, speed up the adoption of lighter, smaller ICE vehicles and upgrade and optimize powertrains. This will also be a major driver pushing transportation sector oil consumption to a peak before 2025. By 2030, China's average oil consumption per 100 km by new passenger cars is expected to drop to 3L, a savings of more than 50% relative to current levels of energy use. Average fuel consumption per 100 km by commercial vehicles is expected to reach the level of advanced countries.

Freight transportation accounts for more than 60% of China's total transportation sector oil use, which makes freight trucks another huge source of energy savings. Through the use of the existing, mature and cost-effective technologies, the SuperTruck initiative launched by the US Energy Department has already improved heavy-duty truck freight efficiency by over 50%. In this area, China can achieve a more dramatic reduction in energy consumption by improving truck manufacturing and equipment, developing swap body transportation, and optimizing logistics organization and management. Driven by the innovation and upgrading of "Made in China", advances and breakthroughs in general technologies, such as green and intelligent manufacturing and advanced composite materials, will also help continuously improve vehicle energy efficiency, thus producing greater spillover effects for the transportation sector to cut energy use, pollutants and carbon emissions.

The Chinese government began managing passenger vehicle makers' fuel economy level in 2013, a policy that has played a positive role in improving fuel economy for motor vehicles. In response to NEV development, in September 2017 the Ministry of Industry and Information Technology (MIIT), Ministry of Finance, Ministry of Commerce, General Administration of Customs and General Administration of Quality, Supervision, Inspection and Quarantine jointly released the *Measures on Parallel Governance of Passenger Vehicle Corporate Average Fuel Consumption and New Energy Vehicle Credits*, which creates the "dual-credit" scheme—corporate average fuel consumption (CAFC) credit scores and new energy vehicle (NEV) credit scores. Despite the "parallel administration", NEVs are linked to the calculation of credit scores in two areas. First, the positive factors of NEVs can be counted in the calculation of CAFC credit scores, meaning that the more NEVs a company produces, the lower its fuel consumption will be. Second, a company's credit score deficit can be offset by an NEV credit score surplus or by purchasing NEV credits from another company.

On July 2, 2019, the MIIT and three other ministries jointly released the calculation results of the 2018 "dual-credit" scheme and started trading 2018 credit scores. On July 9, the four ministries again introduced an amended draft policy on the "dual-credit" scheme, seeking public feedback on the revisions. The amendment would not only lift fuel efficiency compliance standards, but would also raise the threshold for attaining NEV credit scores and lower the credit value per NEV produced, boosting NEV development. According to the updated calculation method, the credit score for a battery electric vehicles (BEV) has been reduced by half relative to the current level. The credit score for a plug-in hybrid vehicle has been reduced by 0.4 points, from the current 2 points to 1.6 points. The credit score for a hydrogen energy vehicle has also been cut by half relative to the current level. Moreover, the previously decisive role of rdriving ange in BEV's credit score calculation has also been weakened in order to guide companies to be more pragmatic and efficient in EV development. Additionally, the comprehensive electricity consumption of a BEV now carries more weight in calculation. This means that the more energy efficient a BEV is, the higher its credit score[35].

2.3 Reduce oil consumption by 25 million metric tons through developing railway and public transportation and optimizing transportation sector structure

Currently, China has already built the world's second longest railway and highway network as well as the longest high-speed railway network. In 2017, the volume and turnover of passengers transported by high-speed railways respectively reached 1.67 billion and 471 billion person-km, up 239% and 142% respectively from 2012. Compared with 2012, the volume and turnover of passengers travelling by railway as a share of the total increased by 27.2% and 15.0% respectively[36]. China's constantly improving multimodal transportation network, with high-speed railways and public transportation at its core, has provided the physical conditions for continuously optimizing the structure of its passenger and freight transportation. The accelerated development of rail transit systems in densely populated areas and the deepened reform of railway management systems will also help reverse the trend of railways carrying a gradually smaller share of freight and instead make railways more competitive in transporting both passengers and goods. Transporting goods through efficient modes such as railways and waterways will help China reduce transportation sector oil demand.

Compared with developed cities like Tokyo, New York City and Hong Kong, China still has a long way to go in areas such as improving public transportation infrastructure, services and the modal share in megacities. The strategy of "prioritizing public transportation" has not been effectively implemented in terms of urban planning, funding support, land supply and right of way allocation. As granting migrants local residency becomes an urbanization priority, putting public transportation at the center of urban development—particularly in terms of metropolitan area and city cluster development—and speeding up the connection of public transportation infrastructure will not only contribute to significant reductions in energy use and carbon emissions, but will also promote integrated and coordinated development for regional populations and economies.

Studies show that planning urban functions efficiently and turbocharging the development of public and non-motorized

TABLE 5.2: COMPARISON OF TRANSPORTATION IN SELECTED CHINESE CITIES

CITY	MOTOR VEHICLES (MILLION)	MODAL SHARE OF PUBLIC TRANSPORTATION	LENGTH OF RAILWAY IN OPERATION (KM)
Beijing	5.64	72% (downtown)	608
Chengdu	4.52	> 50%	179
Chongqing	3.71	59.3%	264
Shanghai	3.54	50.2%	617
Shenzhen	3.22	< 60%	295
Shijiazhuang	2.47	< 30%	30.3
Hangzhou	2.44	< 60%	117.6

Source: Green Travel Trends Report, 21st Century Economic Research Institute, February 2018

35 Measures on Parallel Administration of Passenger Vehicle Corporate Average Fuel Consumption and New Energy Vehicle Credits (revised for public feedback), Ministry of Industry and Information Technology, July 2019

36 2017 Statistical Bulletin of the Development of the Transportation Industry, Ministry of Transport, March 2018

transportation can significantly reduce miles driven by motor vehicles in cities. In Shenzhen, for example (see Table 5.2), there are about 3.22 million motor vehicles and 295 km of railways, respectively equivalent to 57% and 49% of those of Beijing. However, its modal share of public transportation is 60%, very close to that of Beijing, making Shenzhen more efficient than Beijing in urban function and road planning.

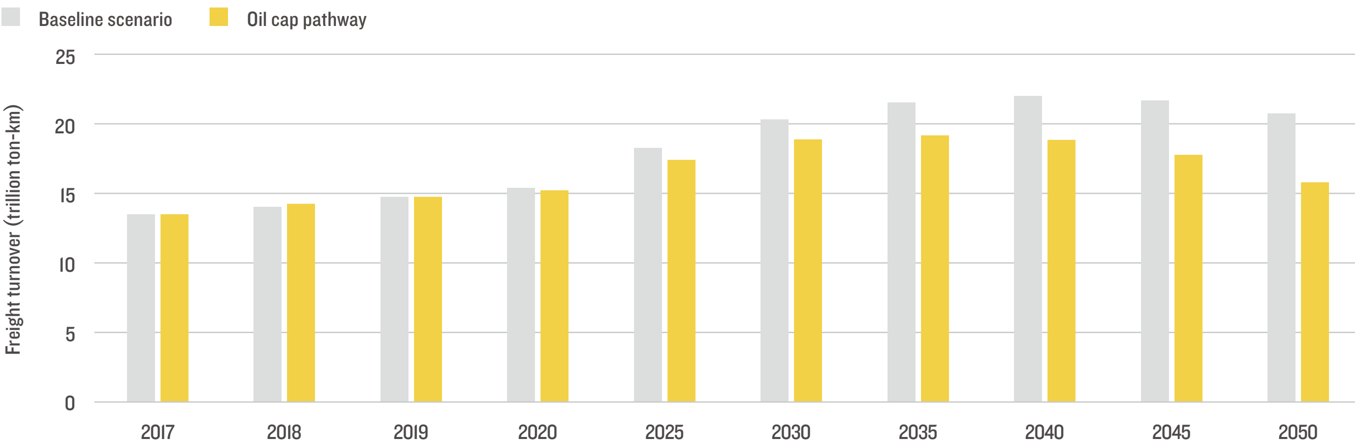
2.4 Reduce oil consumption by 15 million metric tons through optimizing the deployment of industries and urban development models

Foreign and domestic experience in development shows that in the late stage of industrialization, accelerating the adjustment of economic and industrial structures, particularly reducing dependence on heavy chemical industries and implementing an urbanization model that coordinates the development of regional large, medium and small cities, will significantly reduce the transportation of commodity goods such as coal, oil and iron ores, as well as unnecessary transportation distances. Currently, China's freight transportation intensity per unit of GDP is three times as high as that of developed countries like the US and Australia, which indicates considerable room and potential for freight transportation in China to reduce energy consumption[37].

By further adjusting the industrial structure and constantly improving the deployment of manufacturing capacities, all while staying behind mandatory environmental and resource "red lines" in this process, China will significantly slow demand growth for freight transportation. Our analysis shows that by speeding up industrial upgrading, coordinating the development of large, medium and small cities and developing compact cities and city clusters, China will be able to reduce its freight turnover under the oil cap pathway by 11% by 2035 and by 23% by 2050 relative to baseline scenario levels.

China can also significantly reduce motorized travel needs by adopting the following measures—guiding cities to follow an integrated approach to urban development; developing compact cities; encouraging cities to organize intra-city spaces around people, adopting mixed function development and building small blocks and more pedestrian facilities; promoting telecommuting, video conferencing, intelligent traffic signals and congestion alleviation. Many cities in developed countries are already rethinking and transforming their traditional urban development models, having proposed concepts such as new urbanism and smart growth, which put livability at the heart of city development. Copenhagen in Denmark has made the development of bike lanes a priority in its urban planning, with an aim to create the world's most bike-friendly environment. By contrast, the percentage of people travelling by bike is much lower in many Chinese cities.

FIGURE 5.6: FREIGHT TURNOVER UNDER DIFFERENT SCENARIOS



Source: A Study on China's Oil Consumption Scenarios (2015-2050), Sinopec Economics & Development Research Institute, China Oil Consumption Cap Plan and Policy Research Project, June 2019

[37] Reshaping Energy Production and Use to Promote De-oiling, Electrification and Efficiency Improvement in the Transportation Sector, Zhu Yuezhong, Tian Zhiyu and Yin Wenjing, China Economic and Trade Herald Journal, April 2017

China is now at a critical stage of urbanization upgrading. It must completely abandon suburban sprawl and move towards city clusters, a development model connected by inter-city railways and dominated by a mega city surrounded by medium-sized and small cities as satellites. If China follows the transit-oriented development (TOD) model, large amounts of energy, land, water and other resources will be saved.

2.5 Reduce oil consumption by 2 million metric tons through clean fuel utilization

The main purpose of cleaner fuels is to reduce air pollution. In big cities, vehicles' exhaust fumes have become a major source of air pollutants. Over the past few years, the concentration of $PM_{2.5}$ has decreased significantly thanks to various control measures, but ozone pollution has been rising rapidly. China's current nationwide promotion of the Stage VI fuel standard has greatly contributed to the reduction of air pollution. On one hand, the production of high-quality, clean fuel oil necessitates changes in refining processes, resulting in additional costs and more energy consumption. On the other hand, clean fuel oil will help keep engines clean and efficient and extend the service life of components. A widespread use of clean fuel oil will lead to oil reductions on the order of millions of metric tons.

Clean production should be preceded by clean design, which minimizes the consumption of raw materials, energy and water at the source. This in turn minimizes pollution and wastes, so as to reduce the energy consumption and costs associated with waste treatment.

3. THE AUTOMOBILE REVOLUTION HAS GIVEN RISE TO NEW FORMS OF TRANSPORTATION

The rise of NEVs will not only replace and eliminate traditional ICE vehicles, create new value chains and advance technological progress, but will also create opportunities for the application and connection of new industries and IT, elevating "the automobile plus IT revolution" to new heights.

3.1 Guide domestic (both joint-venture and sole proprietor) vehicle companies to establish NEV development as a strategic priority

China has been the world's largest auto market for 9 consecutive years and the auto industry has become a pillar of the national economy. Despite the growing number of vehicle makers and brands, technologically China remains far behind its counterparts such as Europe, the US, Japan and South Korea. China needs to transition from a sizeable auto maker into a strong auto maker by phasing out outdated capacities, strengthening independent innovation capabilities and developing globally competitive, leading automotive companies. NEVs are a new phenomenon. China is already at the forefront of NEV technology and therefore is better positioned to transform the auto industry through NEV development. This would be an automobile revolution and is a clear path forward for China to become a strong player in the global auto market. In fact, energy-saving and new energy vehicles have been clearly defined as the major future direction for China's auto industry in a number of strategic plans, including *Made in China 2025,* the *Development Plan for the Automotive Industry* and *the 13th Five-Year Plan for the Development of Strategic Emerging Industries.*

In July 2018, the National Development and Reform Commission released the *Regulations on the Investment Management of the Automotive Industry (Draft for Comment),* which in principle suspends the investment of new ICE vehicle projects targeting the domestic market and requires traditional ICE vehicle manufacturers to accelerate their NEV transition, so as to drive the overall upgrading of the entire automotive value chain, including production and operational models, means of production and talent pool.

Under the guidance of relevant industrial policies, Chinese companies have gained insights into future automotive trends, and a number of companies, including BYD, NIO and Xiaopeng, have emerged to mainly produce NEVs. At the same time, traditional auto companies, such as BAIC Group and SAIC Motor, are also making active inroads into the NEV market. Moreover, international auto giants are also tapping into China's NEV market. For example, Tesla's super factory in Shanghai is scheduled to be completed by the end of 2019 and is expected to produce 500,000 battery electric vehicles a year for the next two or three years. Toyota has announced partnerships with Chinese battery makers CATL and BYD in terms of battery supply and R&D. BMW has concentrated its technological and R&D resources in EV and other new technologies. In this context, the Chinese government needs to leverage its policies and its huge market to guide various kinds of auto makers to participate in the R&D and mass production of NEVs and send clear signals

TABLE 5.3a: PLANS AND ACTIONS BY INTERNATIONAL MAJOR AUTO MAKERS

COMPANY	GLOBAL NEV PLAN	NEV ACTIONS AND PLANS IN CHINA	NEV TECHNOLOGY ROADMAP
Volkswagen	Roll out 70-plus electric models and produce 22 million EVs by 2028; BEV will make up 40% of its total sales by 2030	Established a NEV joint venture with JAC	BEVs and plug-in hybrid electric vehicles (PHEVs)
Daimler	Electrify all passenger vehicles and roll out 10-plus electric models by 2022; BEVs will account for 15%-25% of its total sales by 2025	Established a joint venture with Geely to develop the next generation of electric smart® cars	BEVs and PHEVs
BMW	Roll out 25 new energy models by 2025, including 12 BEV models	Established a NEV joint venture with Great Wall Motors	BEVs and PHEVs; develop fuel cell vehicle (FCV) technologies
Toyota	An electric version for all models by 2025; ICEs will be removed from all models by 2050	Introduce first BEV model into China in 2020	Hybrid Electric Vehicles (HEVs), PHEVs and FCVs
Honda	NEVs will account for two thirds of its total sales by 2030	Roll out over 20 electric models in China before 2025	BEVs, HEVs, PHEVs and FCVs.
Nissan	Sell more than 1 million NEVs annually starting from 2022	The Renault-Nissan-Mitsubishi Alliance has established a NEV joint venture, eGT, with Dongfeng Motor Group	BEVs, HEVs, PHEVs
GM	Roll out 20 new BEVs by 2023	Roll out 10 electric models in China before 2020 and double its NEV models in the subsequent 3 years	BEVs, PHEVs; focus on developing hybrid and FCV technologies
Ford	Roll out 40 new energy models by 2022, including 16 BEV models	Established a NEV joint venture with Zotye Auto	BEVs and PHEVs
PSA	Roll out 15 electric models before 2021; there will be an electric or hybrid version for all models before 2025	Secure over two thirds of sales in Chinese market are BEVs by 2025	BEVs and PHEVs
Jaguar Land Rover	There will be an electric version for all new cars by 2020	Has entered into an agreement with the Changshu Economic & Technological Development Zone to build a NEV manufacturing facility and a R&D center.	BEVs and PHEVs

Source: China EV100, 2019

TABLE 5.3b: ELECTRIFICATION PLANS FOR DOMESTIC AUTO COMPANIES

COMPANY	NEV PLAN	NEV TECHNOLOGY ROADMAP
Geely	Blue Geely Initiative: By 2020, NEVs will make up 90% of its total sales; PHEV and HEV sales will account for 65% and BEV sales, 35%; Sell 1.8 million NEVs by 2020.	BEV, PHEV, HEV and methanol vehicles in the future
Changan	Mission Shangri-La: build three special platforms for NEVs before 2020; terminate the sale of traditional ICE vehicles and electrify all models by 2025; roll out 21 BEV models and 12 PHEV models before 2025.	BEVs and PHEVs
BAIC	Terminate the sale of traditional ICE vehicles in Beijing by 2020 and the sale and production of traditional ICE passenger vehicles across the country by 2025.	BEVs
SAIC	Roll out over 30 new energy models and sell 600,000 NEVs by 2020, including 200,000 proprietary NEVs.	BEVs and PHEVs
GAC	Has established GAC NE, whose target is to produce and sell 200,000 NEVs by 2020, with more than 20 models. NEVs will account for 10% of the Group's total sales.	BEVs
BYD	Completely replace silicon-based IGBT with SiC MOSFETs by 2030.	BEVs and PHEVs
JAC	NEVs will account for 20% of its total sales by 2020 and 30% by 2025; roll out 7 new energy models before 2020.	BEVs and PHEVs
Chery	Produce and sell 200,000 NEVs by 2020.	BEVs and PHEVs
Dongfeng	Roll out more than 20 electric models under all its brands, including Nissan (Dongfeng), Venucia, Infiniti and Nissan (Zhengzhou) and use e-Power technology in all the brands.	BEVs and HEVs
NIO	Roll out 5 models in the next 5 years: compact SUV ES3, Cross Coupe ET5, sedan ET3, mid-size SUV ES6 and MPV EF9.	BEVs
XPeng	Launch a B-class battery electric sedan and roll out the third model between 2021 and 2022, which are B-class SUVs with Xppilot 4.0.	BEVs
Leap Motor	The first five-door, four-seat mini vehicle based on the T platform will be launched in 2019; the second compact vehicle based on the S platform will be launched in 2020; the first crossover electric SUV based on the C platform will be rolled out in 2021.	BEVs
Qiantu	Produce K20 in 2019, the two-door, four-seat K50 in 2020, the coupe HG13 (four-door, four/five-seat) and K20 (four-door, four-seat) in 2021, and HG15 in 2022.	BEVs

Source: China EV100, 2019

to investors to reinforce an NEV revolution involving a large number of competing market participants in a race to the top.

Internationally, mainstream auto makers have also rolled out NEV development plans and strategies. Every move and investment by these companies is being closely watched. A revolutionary automobile race is happening now, in which participants are competing much more fiercely than expected. Domestic and joint-venture auto companies are also actively taking actions to embrace this electrification wave (see Table 5.2a-b).

3.2 The rise of electric vehicles has created opportunity for the energy storage industry

By the end of 2018, China put 31.3 GW of energy storage projects into operation, including 1.1 GW of photochemical energy storage projects, 2.8 times as much as in 2017[38]. China's 13th Five-Year Plan sets a goal of reaching international advanced levels in energy storage technology and accomplishing the preliminary target of energy storage technology commercialization. During the 14th Five-Year Plan period, China will aim to achieve a nationwide mass commercialization for the energy storage industry[39]. For example, the development of lithium batteries is closely associated with fast growth in the EV market, which has been constantly driving down the cost of lithium batteries. This helps create technological breakthroughs, promoting the rapid development of sodium-sulfur cell technologies as well as technological breakthroughs in flow batteries and their convergence with lithium batteries. On the power generation side, energy storage can help address the fluctuations and intermittency of renewable energy. On the consumption side, energy storage can facilitate electrical load management and demand side response. It is estimated that by the end of 2019 China will have 1.9 GW of electrochemical energy storage projects in operation. By 2023, this capacity will expand to 20.0 GW[40]. For power grids, the focus is on the use of EVs as mobile energy storage devices.

Table 5.4 is a list of energy storage markets and applications in the power sector. Batteries are an important cost component of EVs and batteries retired from EVs are valuable energy storage devices. Additionally, the downgraded use of those batteries can also help compensate for their high costs. Increased competition and R&D spending in China's battery sector will improve the quality of batteries while lowering their cost. Chinese battery makers such as CATL and BYD are already among the world's largest manufacturers, but they need to address challenges such as how to utilize the multi-dimensional value of EV batteries, compensate for high prices, improve product safety and cruising ability.

TABLE 5.4: APPLICATION MARKETS FOR ENERGY STORAGE BATTERIES IN THE POWER SECTOR

SEGMENT	APPLICATION
Generation	Frequency control, spinning reserve, load balancing and output optimization
Transmission	Transmission stability, reactive power support, load balancing, reliable supply and power quality assurance
Distribution	Load management, reactive power support, power quality assurance and reliable supply
Consumption	Power quality, reliable power and voltage support

38 2019 Energy Storage White Paper, China Energy Storage Alliance, May 2019

39 Energy Storage Blue Book, China Energy Storage Alliance, December 2018

40 2019 Energy Storage White Paper, China Energy Storage Alliance, May 2019

3.3 Promote innovative models such as green logistics and shared transportation

Promoting green logistics can also significantly slow down the speed of oil demand growth. Currently, the empty-loaded rate for logistics vehicles is 45%, much higher than that of the US and European countries, which stands at about 20%. China's swap body transportation rate is only 1%, far lower than that of the US and European countries, which is about 80%[41]. In terms of urban delivery services, JD, SF Express, Cainiao and other delivery service providers have already developed plans to replace their transportation tools with NEVs. This has already been implemented in some big cities. In terms of inter-provincial transportation, the Ports of Tangshan, Tianjin and Yantai in the Bohai Economic Rim have completely banned the use of diesel trucks to transport coal, which has greatly reduced the use of heavy-duty diesel trucks in coal transportation. Apart from electric light-duty and fuel cell trucks, Chinese vehicle companies are also researching, developing, testing and investing in heavy-duty trucks powered by electricity, hydrogen energy and LNG. As China implements more such policies and rolls out more such products in the future, logistics sector oil consumption will be dramatically reduced.

In terms of new business format development, China can also dramatically reduce the transportation sector's oil consumption by promoting ride sharing and car-sharing. Transportation models such as bike sharing, which is an effective solution to the "last mile" commute problem, and E-hailing and carpooling models, which focus on short-distance urban travel, can effectively reduce motorized travel needs. For example, shared bikes can be an effective substitute for private cars and taxis and have helped reduce China's fuel consumption. It is estimated that in 2018 alone shared bikes helped the city of Hangzhou save 8.9 million liters of gasoline, which represents 0.4% of the city's total transportation sector gasoline use[42]. When seen from a nationwide perspective, gasoline savings achieved by shared bikes would be really an extraordinary accomplishment.

In business model innovation, Chinese logistics companies still have a lot of potential to exploit in terms of developing shared third-party logistics services and networked transportation. Unlike traditional point-to-point transportation models, these two logistics models can integrate the needs of multiple customers in the same area and enable coordinated transportation arrangements in terms of date, number of trips, route and quantity of delivery, which offers considerable fuel and cost savings. For example, Yuan Cheng Group (YCG) has integrated the transportation business of 20 companies in Chengdu, Sichuan Province. Through YCG's shared logistics services, the 20 companies have achieved an estimated 50% reduction in the number of transportation vehicles, an 86% increase in vehicle utilization, a 36% growth in average utilized load capacity, a decrease of 17,600 km in the total distance driven by transportation vehicles, and a daily saving of 3,500 liters of diesel[43].

3.4 Reduce and replace fuel oil in offshore and inland shipping

China transports the largest amount of freight through inland and offshore shipping lanes in the world and is one of the busiest countries in terms of ocean shipping. Of the world's top 10 ports, 7 are located in China. Shipping has become a major source of air pollutants and carbon emissions. An report by International Maritime Organization (IMO) points out that with expanding global trade, the shipping industry has been producing a growing share of carbon emissions. Due to increased pollution caused by offshore and inland shipping and ports, the IMO will enforce a rule for ships to use fuel oil with sulphur content of no more than 0.5% outside the Emission Control Area (ECA). Many countries have also made it mandatory for ships to dock using ports' electric power supply systems rather than the electricity generated themselves. Many shipping companies have also researched, developed and experimented with electric drive systems to become more competitive economically.

The Ministry of Transport of China has designated ECAs in the

[41] Policy and Strategy Research on Saving Energy and Reducing Carbon Emissions in China's Freight Transportation, Tsinghua University, March 2018

[42] The Carbon Reduction Pathways for the City of Hangzhou under Oil Cap Scenario, Institute for Transportation and Development Policy, China Oil Consumption Cap Plan and Policy Research Project, June 2019

[43] A Study of China's Oil Consumption Peak and Cap Pathways and Measures (for internal use), Energy Research Institute of the National Development and Reform Commission, China Oil Consumption Cap Plan and Policy Research Project

Pearl River Delta, Yangtze River Delta and Bohai Economic Rim to encourage ships to use fuel oil with less than 0.5% sulfur (which contains 80% less carbon than standard marine fuel oil) when entering ECAs. In early 2019, China extended the low-sulfur fuel standard enforcement to all regions within 12 nautical miles (22 km) of its coastline. The success stories of China and other countries prove that the uptake of low-sulfur fuel oil has significantly reduced the concentration of SO_2, $PM_{2.5}$ and nitrogen oxides in the surrounding areas of port cities. Given that it is home to the world's largest inland and offshore ship fleets, as well as many large-tonnage fishing vessels, China has put the development of electric drive systems on its agenda. The country is also pushing ahead with the demonstration of electric inland ships and the use of shore power in the ports of Hong Kong, Guangzhou and Shanghai[44].

3.5 Fuel oil changes in the civil aviation sector

The International Civil Aviation Organization (ICAO) points out that total CO_2 emissions from aviation (domestic and international) account for approximately 2% to 3% of total global CO_2 emissions. If left unchecked, this percentage could expand to 30% by 2050. China has one of the fastest-growing civil aviation sectors in the world. In the foreseeable future, China will have the third largest jetliner manufacturer after only Boeing and Airbus, which means its civil aviation sector will consume more fuel oil and produce more carbon emissions. To fulfill its pollution and carbon emission reduction targets, China can turn to biofuels, develop hybrid engines, and develop and use electric airplanes. Before 2019, more than 170 projects that develop and use zero-emission airplanes had been launched globally. 2020 will see the number of electric airplane R&D projects increasing to 85[45]. The benefit of lower flying costs has already been demonstrated by pure electric light airplanes. We expect more airplane companies and more countries to allocate R&D resources into this field. The R&D of electric airplanes has already become a hot spot among European companies. In 5 to 10 years from now, China will become the word's largest civil aviation market, as well as the fastest growing producer of carbon emissions. Given the common starting point, China's civil aviation sector should join its international peers in researching and developing electric airplanes, so that the country will become a participant, contributor and leader in reducing carbon emissions in this new domain.

[44] A Review of Incentive Scheme for Promoting Green Shipping, National Resource Defense Council, February 2018

[45] Western Media: Electric Airplanes Becoming R&D Hot Spot for European Companies, Can Kao Xiao Xi, August 19, 2019

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6

OIL CAP PATHWAYS FOR THE PETROCHEMICAL AND OTHER SECTORS

The petrochemical sector is seeing the fastest oil consumption growth of all sectors, accounting for 15.3% of oil use in 2017. As many ethylene, paraxylene (PX) and Propane Dehydrogenation (PDH) projects will be put into operation in the future, China will see petroleum increasingly used as a petrochemical feedstock, and the petrochemical industry will become a new driver of oil demand in the country. To reasonably adjust the growth speed of oil demand in the petrochemical sector, China needs to make informed judgments regarding shifting supply and demand curves in the petrochemical market, coordinate domestic and international markets, make significant adjustments to the national planning of petrochemical capacities and process selection, and profoundly transform the way plastics, rubber and other downstream products are consumed. With these oil cap measures, the oil consumption from producing low-value petrochemical products will decrease despite growth in overall demand.

Other oil consuming sectors include industry (non-petrochemical), agriculture, construction, lifestyle, and the wholesale and retail sectors, whose combined oil use accounted for 27% in 2017. In tandem with progress in industrialization, urbanization and infrastructure (like roads) development, oil consumption in these various sectors will stabilize and then decline after an initial growth stage. There is also a huge number of fixed and non-road mobile machinery across the country, which consumes huge quantities of energy and causes severe pollution. One critical countermeasure is to tighten energy efficiency and emissions standards for gasoline and diesel engines.

1. OIL REDUCTION POTENTIAL AND POLICY OPTIONS FOR THE PETROCHEMICAL SECTOR UNDER THE OIL CAP PATHWAY

By 2050, petrochemical sector oil consumption will be 50 million metric tons less under the oil cap pathway than under the baseline scenario. As shown in Figure 6.1, demand reduction measures—such as restricting and recycling plastics, controlling the scale of petrochemical capacities, and reducing oil consumption embedded in exports of products—will result in a 38% reduction. Structural optimization measures, such as mobilizing resources globally and increasing the import of basic chemicals, will achieve a savings of 30%. Efficiency improvement actions, such as increasing petrochemical sector energy efficiency, increasing the value added from extended industry value chains and optimizing the sector's energy mix, will contribute a 20% reduction. Replacement measures, such as developing non-petroleum-based chemical products, will also contribute a 10% decrease. Clean use measures like promoting clean design and production will contribute another 2% reduction.

China is currently at a critical milestone on its journey of advancing its energy revolution and ecological civilization. The highly polluting and energy-intensive petrochemical sector must meet the requirements of this endeavor in terms of its positioning, operating model, production process and product portfolio. An integral component of China's pursuit of quality and green development for the sector is to facilitate a reasonable growth in its oil use. This needs to be achieved

FIGURE 6.1: REDUCTION POTENTIAL AND APPROACHES FOR THE PETROCHEMICAL SECTOR BY 2050

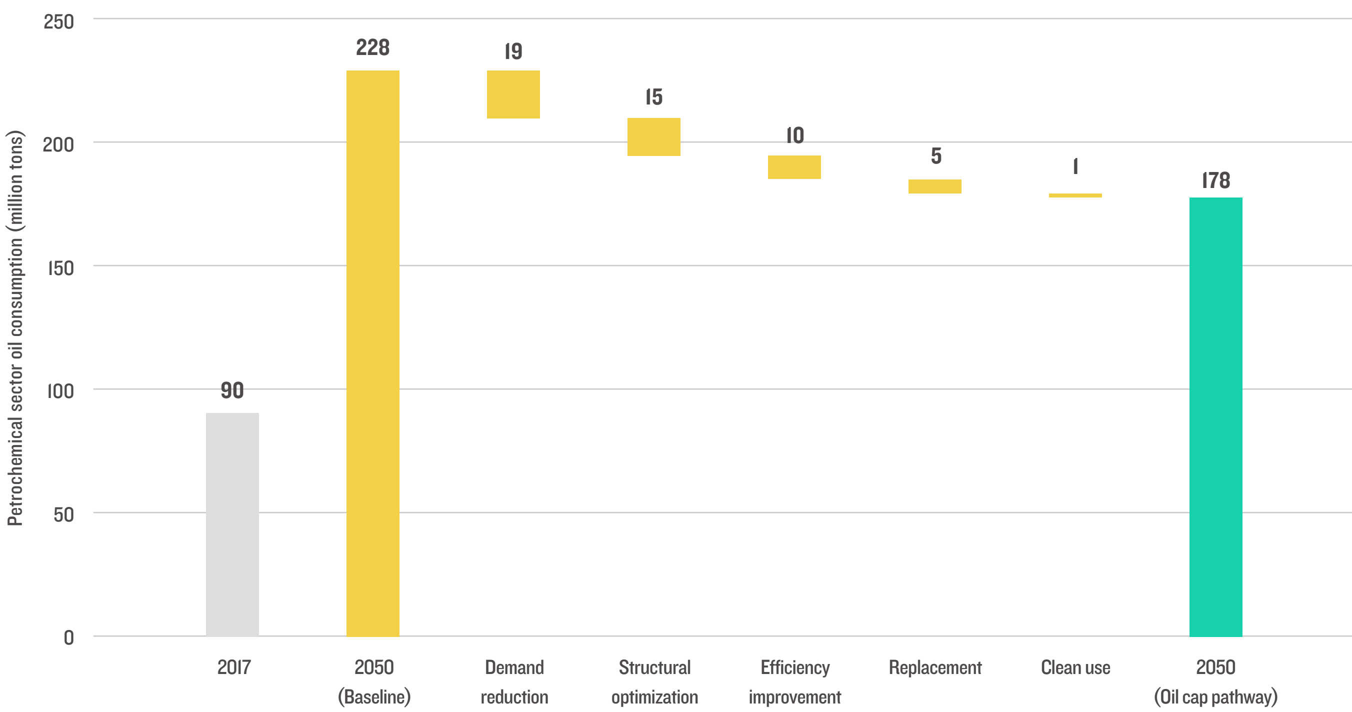


TABLE 6.1: ILLUSTRATIVE POLICY OPTIONS AND OIL CAP MEASURES FOR THE PETROCHEMICAL SECTOR

APPROACHES	KEY AREAS	EVALUATION INDICATORS	POLICY OPTIONS AND MEASURES
Demand reduction	Reduce the export of energy- and oil-intensive products	• Plastic product exports • Rubber tire exports • Exports of products like chemical fiber and textiles • Ethylene exports • Naphtha exports	1. Improve import and export tax policies to appropriately control export volume 2. Remove tax incentives for the export of low-value petrochemical products 3. Strictly control the export of petrochemical raw materials and products
	Restrict and ban the production and use of general plastics	• Plastic use reduction and plastic replacement • Recycling rate of plastics • Types of plastics banned from production	4. Publish a timetable and a roadmap for the restriction and ban of plastics 5. Raise the cost of using non-degradable plastics
	Increase the recycling of chemical products	• Recycling rate of plastic waste • Recycling rate of waste rubber tires	6. Introduce incentive policies for plastic recycling 7. Introduce tax incentives to support the resource recycling industry 8. Increase investment in technologies enabling comprehensive and high-value utilization of resources 9. Improve community recycling networks 10. Establish an extended producer responsibility system
Efficiency improvement	Improve resource and energy efficiency	• Oil use per unit of ethylene output • Oil use per unit of PX output • Increases in the energy efficiency of process and energy-consuming equipment	11. Continue to implement the Energy Efficiency Leadership Scheme and the energy efficiency benchmarking campaign in the petrochemical sector 12. Strengthen intelligent and IT-based management among petrochemical companies 13. Pilot different resource utilization metrics
	Optimize production capacity and product portfolios	• The average capacity of refineries in China • The output share of special grade petrochemical products	14. Establish the criteria for defining outdated capacities based on material consumption, energy use, environmental friendliness, safety and product quality 15. Strengthen efforts to phase out outdated, small capacities with obsolete production processes
Replacement	Biomass	• Degradability • Harmlessness	16. Incentivize mass production 17. Replace petroleum-based raw materials
	Natural gas	• Cost • Natural gas-based raw materials	18. Encourage market-driven competition 19. Replace petroleum-based raw materials
Structural optimization	Diversify product supply sources	• Ethylene equivalent imports • PX imports • Naphtha imports • Overseas capacity investment	20. Encourage industry leaders to "go global", build factories overseas, and capitalize on global resources and markets 21. Provide policy and funding support to globalizing companies whose operations are aligned with the Belt and Road Initiative 22. Establish a green indicator system and strengthen cooperation in green manufacturing capacity
	Diversify sources of raw materials and manufacturing processes	• Share of the naphtha-to-ethylene production process • Share of non-oil-based production processes like the ethane-to-ethylene process	23. Encourage projects such as ethane cracking and PDH where there is an adequate supply of resources and mature technologies 24. Properly develop the coal-to-olefins industry 25. Strengthen efforts in the development and piloting of cutting-edge technologies such as ethane-to-ethylene technology
Clean use	Clean design, production and recycling	• Clean design at source • Treatment of waste air, wastewater, solid and hazardous wastes • Increases in product life cycles and recycling of interchangeable parts	26. Minimize environmental impact and resource consumption and ensure that products can be reused 27. Develop and implement standards along with rewards and penalties 28. Impose rigorous safety standards and particularly, stricter regulations on wastewater and hazardous waste management 29. Require producers to use interchangeable parts that can be recycled

in stages, with different levels of priority given to different areas through a combination of approaches, including demand reduction, structural optimization, efficiency improvement and diversification. Priority areas, evaluation indicators, and policy recommendations are provided in Table 6.1.

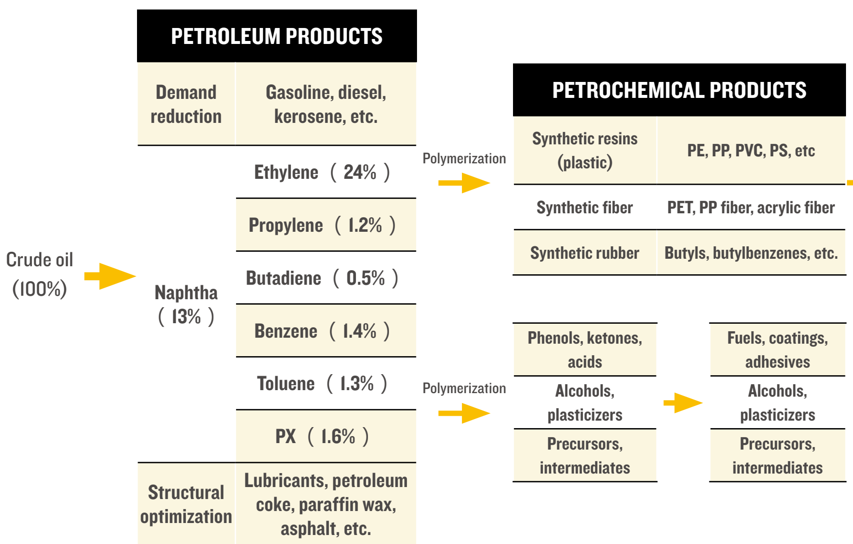
2. SPECIFIC OIL CAP MEASURES UNDER THE FIVE APPROACHES FOR THE PETROCHEMICAL SECTOR

2.1 Reduce oil consumption by 19 million metric tons through restricting the use of single-use plastic products and encouraging eco-friendly designs and resource recycling

Plastic production has a major impact on global oil demand. The International Energy Agency (IEA) forecasts that if the current trend is left unchecked, by 2050 plastic production will reach 1.1 billion metric tons and will account for 20% of the world's oil consumption, producing 15% of global carbon emissions. By then, about two thirds of crude oil in the petrochemical sector will be used for plastic production. It is estimated that the amount of oil used for plastic production will be more than 2.5 times as much as the average quantity consumed between 2000 and 2017 .

In contrast with China's massive plastic production, recycling rates for plastics remain low, making waste plastics a severe cause of environmental harm. In 2017, China produced about 68 million metric tons of plastic waste—of which 23 million metric tons (34%) were buried in landfills, 19.8 million metric tons (29%) were incinerated, 18.3 million metric tons (27%) were recycled, and 6.55 million metric tons (9.7%) were simply thrown away . A 2014 UNEP report finds that the financial cost of land-based and marine pollution caused by plastics (excluding those which are recycled and properly treated) is as high as 75 billion USD per year, with the overall

FIGURE 6.2: PROCESS FLOW DIAGRAM OF THE PRODUCTION AND CONSUMPTION OF DIFFERENT TYPES OF PLASTIC PRODUCTS AND THEIR REDUCTION POTENTIAL



END CONSUMER PRODUCTS	PROD. (Mt)	COE* (Mt)	POTENTIAL REDUCTION APPROACHES	REDUCTION POTENTIAL (Mt)
Supermarket plastic bags, single-use toiletries, straws, cotton buds, etc.	3	3.9	Ban 100%	3.9
Plastic courier packages, woven bags, take-away food containers, food packages, etc.	16	20	Restriction 45%	9
Plastic water bottles, polyester clothes, agricultural films, fishing gear, etc.	42	40	Recycle 70%	28

Note: COE refers to crude oil equivalent

Source: Based on information provided by the China National Petroleum & Chemical Planning Institute, China Petroleum and Chemical Industry Federation, the Professional Committee of Agricultural Films of CPPIA and Sun Wei from Ni'ao Technology

[46] The Future of Petrochemicals, International Energy Agency, October 5, 2018

[47] Speech by Mr. LI Shousheng, President of the China Petroleum and Chemical Industry Federation, at the CPCIC 2019, September 19, 2019

financing damage of plastics to marine ecosystems standing at 13 billion USD each year[48].

As shown in Figure 6.2, crude oil refined for naphtha and other petrochemical feedstocks accounted for about 13% of total refinery input in China in 2017, standing at above 76 million metric tons. The bulk of plastic products, which can be divided into different categories, can be treated in different ways to achieve reductions in oil use.

A complete ban can be imposed on the first category of plastic products, which includes supermarket plastic bags, single-use toiletries, straws and cotton buds, all of which are used in huge quantities and are highly polluting, non-recyclable, non-essential and replaceable. The total production of these plastics stands at approximately 3 million tons. A 100% production ban will reduce crude oil consumption by 3.9 million metric tons. Restrictions can be enforced on the second category of plastics, including plastic courier packages, woven bags, take-away food containers and food packages. Plastics in this category are also used in large quantities, are difficult to recycle and have no effective alternatives. The output of such plastics totals about 16 million tons, representing a crude oil consumption of more than 20 million metric tons. For this category, taxation or mandatory extended producer responsibility can be introduced to limit the use of such plastic products and to encourage manufacturers to find alternatives. These reduction measures are expected to reduce oil consumption by 45%. The third category of plastics are recyclables, which include plastic water bottles, polyester clothes, fishing gear, agricultural films and more, with a total production of 42 million tons. A 70% recycling rate of these plastics can lead to a reduction of 28 million metric tons. Overall, reduction measures targeting the first, second and third categories of plastics can respectively cut crude oil consumption by 3.9 million, 9 million and 28 million metric tons. For different categories of plastics, different policies and implementation timetables are to be developed and implemented[49].

The international community has basically reached a consensus on the restriction and ban of plastics, with many countries having already taken actions. On October 24, 2018, the European Parliament voted overwhelmingly in favor of a ban on the use of single-use plastic items to control damage to the marine and ecological environments, which are being increasingly threatened by plastic pollution. Starting from 2021, the EU will ban the production and sale of single-use plastic products such as disposable plates and cutlery, cotton buds and straws, which will be replaced by alternatives made from paper, crop straw or reusable hard plastics. EU members also target a 90% recycling rate by 2025 for plastic beverage bottles, which will have to be collected separately. In April 2018, the South Korean government released the Comprehensive Countermeasures for Garbage Collection and Reuse, which is designed to cut the use of disposable cups and plastic bags by 35% by 2022 and plastic waste in half by 2030.

In plastic recycling, compared with the naphtha-to-virgin plastic route, recycling can generate considerable economic, energy and environmental benefits. Plastic waste collection allows resources to be reused and thus reduces demand for new petrochemical materials, such as ethylene and paraxylene. It is estimated that 0.85 tons of new plastics can be derived from one ton of recycled plastics, which translates into a saving of 3 metric tons of oil. Producing one ton of plastic products through recycling will only consume 5% of total energy that is otherwise required under the naphtha route. The IEA estimates that a increasing recycling rates to 34% globally would lead to a reduction in oil demand of 1.5 million barrels a day by 2040 compared to its base case scenario.

China's waste plastic recycling rate still has much upside potential. According to the China Association of Circular Economy, the amount of waste plastics recycled in China was less than 20% of its total production in 2017. At the same time, China produces nearly 68 million tons of plastic waste each year. This suggests that China still has a huge gap to fill in terms of both waste plastic recycling rates and volume[50]. Based

[48] Valuing Plastics, UNEP, June 23, 2014

[49] Data from the China National Petroleum & Chemical Planning Institute and Sun Wei from Ni'ao Technology. The oil cap research project team is researching specific oil reduction measures through the ban and restriction of plastics. Research findings will be released in 2020 and some data mentioned herein will be updated.

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on the current share of petroleum used as a petrochemical feedstock in total oil use, a 10% increase in China's plastic recycling rate will lead to a 1% reduction in oil use.

China's efforts to minimize plastic waste in pursuit of circular development in the petrochemical industry should start with enhanced designs to enable subsequent waste recycling, improved recycling systems, upgraded technologies, large-scale organization/administration and the adoption of internet-based recycling models. Given that few effects have been achieved from the "2008 plastic bag restrictions" introduced by the National Development and Reform Commission, the Chinese government is advised to enforce an updated version of restrictions around 2020. First, China should clearly define a binding guideline on the restriction and ban of plastics, set a clear timetable for terminating the production and use of non-degradable plastics, improve waste plastic recycling systems with a clear division of responsibilities between producers and consumers. The guideline should require supermarkets, online shopping platforms, express delivery service providers and take-out food providers to minimize plastic packaging and use alternative materials. Second, China should adopt technologies that enable the efficient sorting and high-value utilization of waste plastics, increase the utilization rates and added value of plastic products through modification or alteration and steer the plastic recycling industry towards a more intensive, high-value and deep processing direction, so as to create a harmonized mix of economic, social and ecological benefits. Third, China should encourage market participants to shift from decentralized, small-scale and low-value recycling to centralized, large-scale and high-value recycling in industrial parks through merging, reorganizing and forming joint ventures. Finally, China should promote creative internet-based recycling models and leverage information technology to streamline resource allocation, reduce intermediate links in the supply chain, increase efficiency and lower operational costs. Along the way, China can gradually extend plastic restrictions to products besides plastic bags.

[50] China Circular Economy Development Report (2018), China Association of Circular Economy, 2019

In its effort to restrict and ban plastics, the Chinese government is advised to capitalize on the strengths of civil society organizations, whose bottom-up approach can supplement the government's top-down policy guidance to maximize impacts. For example, NRDC has joined hands with other organizations to create a platform to promote the banning, restriction and recycling of plastics. The platform engages governments, companies, think tanks, civil society organizations, the media and the general public to champion and promote extended producer responsibility, while encouraging the general public to act on their own initiative to contribute to national goals. It will also support China's nationwide waste sorting and recycling program, the "Zero-waste City" pilot program and the China Zero Waste Alliance. Without public engagement, this effort will end up less effective or even completely fruitless.

2.2 Reducing oil consumption by 15 million metric tons through optimizing the structure of petrochemical imports and exports and diversifying manufacturing processes

While "Made in China" has achieved global success, it also has led to significant, indirect export of petroleum in the form of petrochemical products. Since its accession to the WTO, China has shipped huge quantities of industrial products globally, many of which are downstream petrochemical products, such as garments, plastic products and rubber tires. Some analysts say that oil use embedded in China's exports exceeded 100 million metric tons in 2010. Since then, the country's export of major downstream petroleum products has been growing at varying speeds. In 2017, China's oil use included in its exports reached approximately 130 million metric tons[51].

The growth of petrochemical sector oil consumption can be effectively curbed by reducing the export of chemicals and downstream products. This will help China save oil and strengthen crude oil supply security at the source. According to a report from the China National Petroleum and Chemical Planning Institute, China imported about 25 million metric tons of ethylene and 10 million metric tons of PX in 2017, which altogether represents nearly 80 million metric tons of oil consumption. In the same year, China's oil use embedded in its exported products—including plastic products, rubber tires, textiles and other downstream products—exceeded 130 million metric tons. This resulted in a "deficit" of around 50 million metric tons of crude oil in the sector's "oil account". To reduce this deficit, China can import petrochemical products instead of crude oil. This will not only cut the stranded costs of big investments in petroleum and petrochemical production and reduce the environmental pollution caused by the excessively concentrated chemical industry but will also expand international trade and help create win-win outcomes. In the future, China should improve its existing model of import and export trade as well as its portfolio of imported and exported products to scale back the export of energy-intensive and low-value products, thereby reducing the energy and oil embedded in exported goods. China's petrochemical and other chemical industries should position themselves to satisfy domestic demand while implementing the strategy of gradually cutting oil consumption. Furthermore, China can deepen supply-side structural reforms to reasonably control the export of petrochemical and downstream products to force a shift towards intensive development in the petrochemical sector.

China can also expand its footprint in the petrochemical supply chain and increase the import of primary products while advancing the Belt and Road Initiative. The Belt and Road countries are rich in oil and gas resources, but are short of petrochemical products, a situation that makes them ideal partners for China's petrochemical players as they go global. China should leverage the comparative advantages of its traditional petrochemical companies by aligning their business operations with the initiative and encouraging them to globalize their operations to access more low-cost basic chemicals.

The shortage of refined oil and petrochemical products in Belt and Road markets will not only create opportunities for Chinese companies to expand exports, but also will boost the development of local refining industries, increase investment and cooperation opportunities for both sides, and create more demand for engineering services like refining (see Figure 6.3). Furthermore, setting up joint-venture refineries in oil and gas-rich regions will not only ensure the most appropriate operating

51 An Analysis of the Passive Net Petroleum Export Phenomenon Created by "Made in China", Tang Xu, Zhang Baosheng, Feng Lianyong, et al., Resources Science, Vol. 34, No. 2, 2012

FIGURE 6.3: POTENTIAL FUTURE SOURCES OF ETHYLENE

capacity, but will also allow Chinese companies to select the most favorable conditions in the initial design, construction and operation of refineries, which will maximize their interests.

Meanwhile, regions like the Middle East and North America are gradually showing signs of overcapacity in petrochemical production. In response to the challenge, these regions are actively tapping into overseas markets, a move that perfectly fits with China's strong demand for petrochemical products. Therefore, China should push its competitive industries and companies to accelerate their pace to seek international capacity cooperation and globalize their business operations, for example, by building manufacturing facilities overseas and conducting international trade to access more cheap basic chemicals and raw materials. This will strengthen their competitiveness and global sourcing capabilities. Chinese petrochemical companies first started with petroleum refining and ethylene production in international capacity cooperation. To ensure that capacity cooperation is environment and climate friendly, China has developed a series of green metrics to guide companies to go green and low-carbon in their capacity cooperation.

2.3 Reduce oil consumption by 10 million metric tons through efficiency improvement measures, such as implementing supply-side structural reforms and guiding the petrochemical sector to improve quality and efficiency

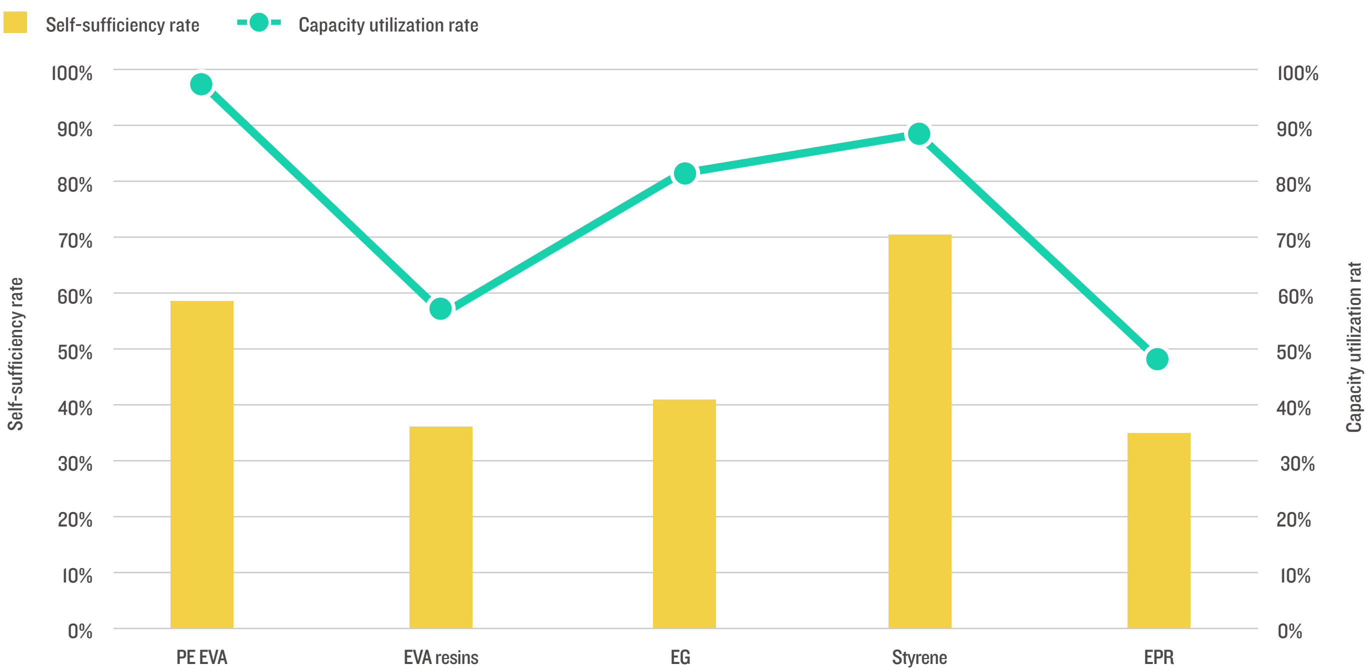
China's petrochemical sector is highly segmented with many small refineries that produce low-value products. In 2018, China's oil refining capacity increased to 830 million metric tons, with crude runs reaching 640 million metric tons, though the capacity utilization rate went down to 72.8%. Chinese refineries only have an average annual capacity of 4.28 million metric tons, which is about 60% of the global average of 7.50 million metric tons.

Apart from its small size, China's petrochemical sector is also characterized by an oversupply of low-value products and an undersupply of high-value products. In 2017, for example, China's net import of polyethylene (PE) amounted to 11.55 million tons, about half of which were higher-value products. China's annual demand for high-quality PE insulation materials used in UHV (110-kV or above) power cables stands at approximately 50,000 tons, almost all of which are supplied by foreign countries. The same is true with polypropylene (PP). Of China's net import of 4.4 million metric tons of PP in 2017, high-end PP accounted for about 60%[52]. Figure 6.4 below shows a contradiction between the capacity utilization rates and the self-sufficiency rates of several major petrochemicals. On the one hand, manufacturers of these chemicals are struggling with an oversupplied market and low capacity utilization rates. On the other hand, China remains far from being self-sufficient and is heavily dependent on foreign suppliers for high-value petrochemicals.

Today, "large-scale, intelligent, green, and refined petrochemical integration" have become keywords for the transformation strategy of global petrochemical companies. China should deepen its supply-side structural reforms to guide petrochemical companies to expand their size, move up the value ladder, make structural adjustments and improve energy efficiency, thereby reducing the sector's oil consumption.

Specifically, China needs to: 1) vigorously push ahead with supply-side structural reforms with a focus on capacity reduction and the phaseout of outdated capacities—China should speed up its pace to phase out small and low-end capacities that still use outdated processes, particularly small refineries, whose combined capacity stands at nearly 100 million metric tons as well as ethylene plants with a capacity below 300,000 metric tons; 2) establish a market-oriented mechanism to facilitate the inter-provincial trading of refining capacities, so as to encourage competitive companies to seek M&A and reorganization opportunities and achieve economies of scale; 3) increase spending on R&D and promote the hi-tech, intelligent, IT-based, energy-efficient and environment-

FIGURE 6.4: CAPACITY UTILIZATION AND SELF-SUFFICIENCY RATES OF SELECTED MAJOR PETROCHEMICALS



Source: Development Pathways for Petrochemical and Chemical Products, Bai Yi, China National Petroleum & Chemical Planning Institute, 2018

[52] Thoughts on the Restructuring of the Light Hydrocarbon Industry under the New Situation of the Refining and Petrochemical Sector (Conference Paper), Cao Jianjun, 2018

friendly transformation of petrochemical products to address the structural problem of "an oversupply of low-value products and an undersupply of high-value products". China may encourage companies to extend their industry value chains, develop proprietary brands and adopt a differentiation strategy by supplying high-value products and upgrading and increasing the value added of their products, with a focus on functional materials such as high-quality clean refined oil, quality lubricants, high-performance additives, intelligent drilling and extraction systems, specialty rubber products, performance tires, functional chemical fibers and carbon fibers.

2.4 Reducing oil consumption by 5 million metric tons through replacing feedstocks and developing non-petroleum-based routes

Diversification of petrochemical feedstocks, by shifting to lightweight hydrocarbon and non-petroleum-based routes for example, has become a major global trend in recent years. Each primary chemical, such as ethylene, propylene and paraxylene (PX), has several production routes that use different feedstocks, including petroleum. For example, ethylene may be produced from crude oil intermediates such as naphtha and hydrocracker bottoms (HCB), through gasification and synthesis of natural gas or coal, or by cracking light hydrocarbons such as ethane.

Driven by cost factors, the global shift toward diverse feedstocks, particularly lightweight hydrocarbons, in the production of ethylene has been quite notable in recent years. The share of the world's ethylene production using the petroleum-based route has dropped from 61% in 2000 to 43.8% in 2017[53]. Particularly, the US shale revolution has seen huge quantities of cheap ethane making its way into the market, which has quickly driven down the cost of ethane-based ethylene production and expanded its production capacity. According to HIS Markit, about 40% of global ethylene supply will come from the ethane-to-ethylene route by 2020, as more North American capacities are put into operation. These developments will also significantly reduce crude oil consumption in petrochemical production.

China has made measurable progress on this front, but still faces a significant gap with developed countries. As of the end of 2016, the petroleum-based route accounted for 81.5% of China's total ethylene capacity and the coal-based route accounted for 18.5%, up from 9.5% in 2014. The petroleum-based route accounted for 63.8% of China's total propylene capacity, the coal-based route accounted for 20.9%, up from 17.7% in 2014, and the alkane dehydrogenation route accounted for 15.3%, up from 9.7% in 2014. Although China has met its target of diversifying 20% of olefin raw materials, which is set out in its *12th Five-Year Plan for the Olefin Industry*, it still has a long way to go to reach the level of developed countries, where the petroleum-based route only accounts for 45% of their olefin capacity. For the foreseeable future, diversifying olefin feedstocks will remain a foremost priority of Chinese industrial policies[54].

Expanding the share of non-petroleum-based production routes is a crucial way to curb petrochemical sector oil demand. Today, production processes such as ethane-to-ethylene, methanol-to-olefins (MTO) and propane/mixed-alkane-to-olefins are quite mature and are being quickly adopted. In the future, they will replace more traditional naphtha-to-olefins and HCB-to-olefins processes and thus further decrease petrochemical sector oil demand. As a new round of investments in large-scale, integrated refining projects will start around 2020, China's ethylene capacity using the naphtha route will be gradually restored between 2020 and 2030 and then stabilize at about 67% around 2030. With the rebalancing of domestic supply and demand and the increased availability of new technology options (including the crude oil-to-olefins, natural gas-to-olefins and new-generation bioethanol processes) in the next investment cycle, the share of naphtha-based ethylene capacity will drop again. It is estimated that China's ethylene capacity will reach 65 to 70 million metric tons by 2050, in which the share of the naphtha-/crude oil-based routes will shrink to about 60%.

While feedstock diversification and substitution are two imperatives for the petrochemical industry and China's energy security, market demand must always be taken into consideration along the way in order to prevent overcapacity that could otherwise result from the lack of coordination among various

[53] An Analysis of the Passive Net Petroleum Export Phenomenon Created by "Made in China", Tang Xu, Zhang Baosheng, Feng Lianyong, et al., Resources Science, Vol. 34, No. 2, 2012

[54] Thoughts on the Restructuring of the Light Hydrocarbon Industry under the New Situation of the Refining and Petrochemical Sector (Conference Paper), Cao Jianjun, 2018

production routes. According to a forecast from the China Coal Processing and Utilization Association (CCPUA), China's olefin capacity will expand at a pace of 15% during the 13th Five-Year Plan period (2016-2020), compared with an estimated 5% growth in demand. If this trend is left unchecked, the undersupplied olefin market will quickly become oversaturated.

While seeking non-petroleum alternatives as petrochemical feedstocks, China must not encourage the rapid development of the coal chemical industry. In some demonstration projects, many coal chemical technologies remain immature or defective and may pose problems for the utilization of environmental and water resources as well as for waste water and gas treatment. In particular, large-scale, reckless development of the coal chemical industry, which is carbon-intensive, will lock China in on a high-carbon path. In terms of economic benefit, except for a very few chemical products, most coal chemical production facilities are located far away from the market and the industry as a whole is still far behind its rival petrochemical industry in terms of technology commercialization and operational efficiency. That is why China must stay alert to the blind development of the coal chemical sector while promoting non-petroleum alternatives as petrochemical feedstocks. Moreover, unchecked growth of the coal-to-olefins industry will largely offset the substantial reduction in coal consumption achieved through coal cap measures, leading to a "return to coal". Over time, the share of natural gas in the energy mix will rise to around 15%. However, natural gas should not be seen as a fuel, but as a feedstock. Looking ahead, the natural gas-based olefins production route will be competitive enough to substitute for the oil-based and coal-based routes. Therefore, another source of oil savings will come from natural gas use.

2.5 Reducing oil consumption by 1 million metric tons through clean production and utilization

Petrochemical production activities have serious side effects on air, water and soil, making petrochemical production a high risk operation. Promoting clean production is not aimed at oil savings—it may even increase oil use—but it can minimize the adverse impacts of chemical production on the environment as well as on resource consumption. China's increasingly tightened environmental, ecological and climate regulations call for continuous improvements in oil quality. On the one hand, changes in manufacturing processes and equipment will result in higher electricity consumption and oil productivity. On the other hand, better oil can extend the service life and operational efficiency of oil-consuming equipment. Furthermore, clean design and production will reduce waste, improve product quality and extend product service life at the source, while increasing the possibility of products being recycled and reused. Overall, clean production can save one million metric tons of oil.

3. REDUCTION POTENTIAL AND SPECIFIC MEASURES FOR OTHER SECTORS UNDER THE OIL CAP PATHWAY

There is a huge amount of oil-consuming equipment in operation in other sectors as well, causing serious pollution and posing challenges for emissions reduction. With increased roads and infrastructure as well as urban development, oil consumption in these sectors will first experience a period of growth, followed by stabilization and then decline.

3.1 Reduction potential for other sectors under the oil cap pathway

Oil consumption in other sectors will reach 102 million metric tons by 2050 under the oil cap pathway, 68 million metric tons less than the 170 million metric tons under the baseline scenario. As shown in Figure 6.5, efficiency improvement measures like imposing stricter energy efficiency standards for gasoline engines will reduce oil consumption by 20 million tons, and reducing unnecessary engineering will reduce consumption by 18 million metric tons. Structural optimization measures like phasing out inefficient production equipment can reduce consumption by 16 million metric tons, replacement measures such as using alternative fuels and electricity can reduce consumption by 12 million metric tons, and clean use measures such as using high-quality fuel oil can reduce consumption by 2 million metric tons. Oil consumption in other sectors is expected to peak between 2025 and 2035.

3.2 Policy options and specific oil cap measures for other sectors

Table 6.2 provides a list of key areas, evaluation indicators as well as policy options and oil cap measures for other sectors.

FIGURE 6.5: REDUCTION POTENTIAL AND APPROACHES FOR OTHER SECTORS BY 2050

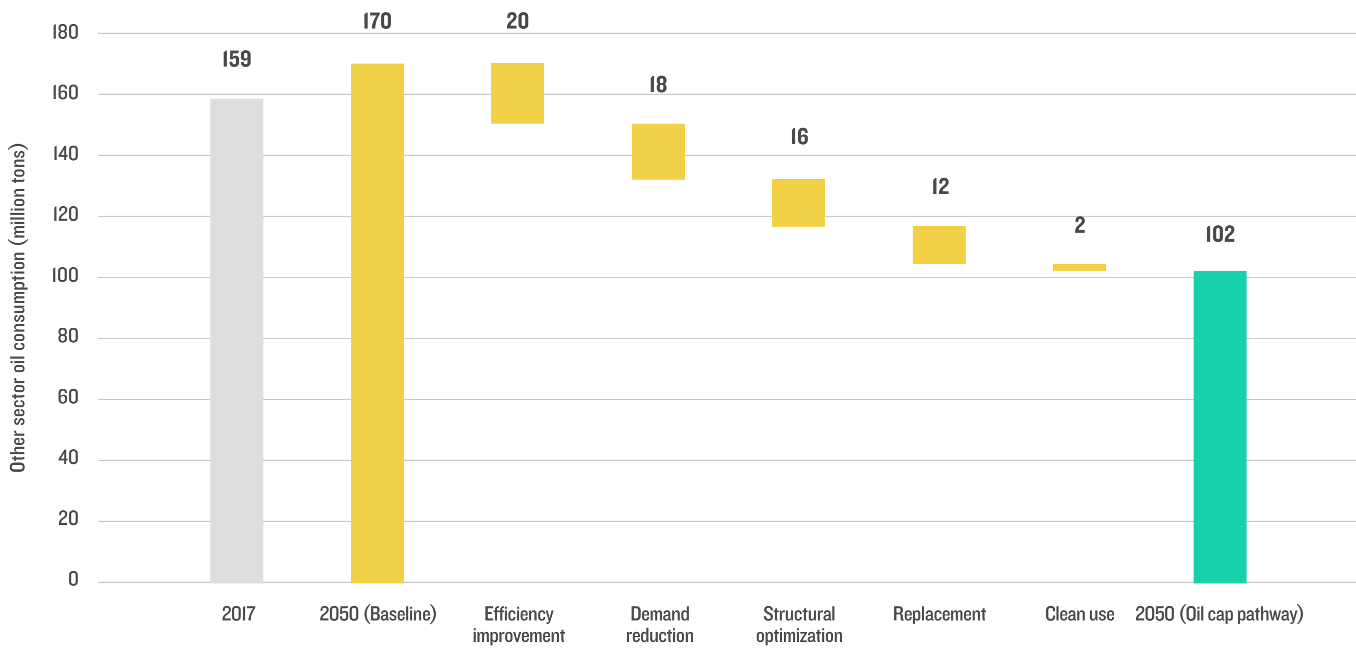


TABLE 6.2: ILLUSTRATIVE POLICY OPTIONS AND OIL CAP MEASURES FOR OTHER SECTORS

APPROACH	KEY AREAS	EVALUATION INDICATORS	POLICY OPTIONS AND MEASURES
Demand reduction	Reduce unnecessary maintenance & repairs for auxiliary equipment and roads	• Reduced equipment and road maintenance & repairs	1. Improve equipment quality 2. Improve road quality grades and use high-quality asphalt 3. Reduce road renovations and major demolition/ reconstruction activities
	Reduce leakage	• Enhanced management	4. Introduce specific measures and guidelines for energy reduction 5. Improve management and training
Efficiency improvement	Impose stricter energy efficiency standards	• Raised energy efficiency standards for main oil-consuming systems	6. Impose stricter energy efficiency and emission standards for gasoline/diesel engines 7. Improve the efficiency of fuel-fired heating systems
	Improve the overall efficiency of mechanical systems	• Properly matched systems as a whole	8. Labelling and markings 9. Issue certificates/licenses for systems; market regulation
Replacement	Develop alternative powers and fuels	• Quantity of fuel oil replaced by electric power • Quantity of fuel oil replaced by biofuels	10. Power fixed equipment with electric power 11. Power supply and use of biofuels for mobile sources
Structural optimization	Optimize industrial processes; phase out outdated equipment and capacities	• Digital optimization • Ban of substandard products • Production regulation	12. Step up market supervision and random checks on products 13. Exit mechanism for unqualified companies
Clean use	Supply high quality oil; use pollutant removal facilities	• Extended equipment service life • Reduced pollutant emissions/discharge	14. Shift to clean fuels 15. Develop standards and introduce annual inspections for pollutant emissions/discharge 16. Promote the use of high-quality industrial lubricants and the like 17. Designate urban industrial zones where non-road mobile sources with high emissions are prohibited

7

PLANS AND MEASURES FOR LOCAL OIL CAP IMPLEMENTATION

The oil cap pathway should not only apply a top-down approach to control the oil consumption of relevant sectors but should also cap oil consumption at the local level using a bottom-up approach. Local governments at all levels should take active and effective measures to achieve oil cap targets in accordance with the local social, economic, political and ecological circumstances within the limits of their authority. By actively promoting excellent local practices they can help to achieve national level goals.

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I. THE CRUCIAL ROLE OF LOCAL GOVERNMENTS IN AN OIL CONSUMPTION PEAK AND CAP

Air pollution in Chinese cities has shifted from pollution solely generated by coal soot to a combination of coal soot and car exhaust. As such, the transportation sector in many big cities has become a major source of pollution. In order to alleviate urban traffic congestion and its impact on the atmospheric environment, some mega- and large-scale cities have begun to implement car purchase restriction policies, which mainly include license plate bidding, a license plate lottery and a combination of both. Shanghai was the first city in China to adopt a motor vehicle license plate bidding system in 1994. Beijing and Guiyang were the first cities to use the lottery method to control the total number of urban motor vehicles. Some cities have begun to adopt a new method that includes a combination of lottery and bidding, instead of using a single method for management. There are also some cities and regions such as Xi'an and Jiangsu that are preparing the formulation of total vehicle control schemes.

In response to the decline of car sales in recent years, the government has adjusted the regulations on car purchase restrictions in certain cities. The National Development and Reform Commission, in cooperation with 10 other government departments, have successively issued the *Implementation Plan to Further Optimize Supply to Promote Steady Growth in Consumption and Promote the Formation of a Strong Domestic Market (2019)*, and the *Implementation Plan for Upgrading Key Consumer Goods and Recycling Resources (2019-2020)*. These documents require all local governments to actively promote car consumption and forbid the release of new automobile purchase restrictions. They also encourage exploration into ways to gradually relax or cancel restrictions on automobile consumption. Cities such as Guangzhou and Shenzhen responded to these national policies with an increased quota for passenger cars. Guiyang became the first city to remove car purchase restrictions. Even so, some cities still maintain their restrictions on ICE vehicles while encouraging people to buy NEVs.

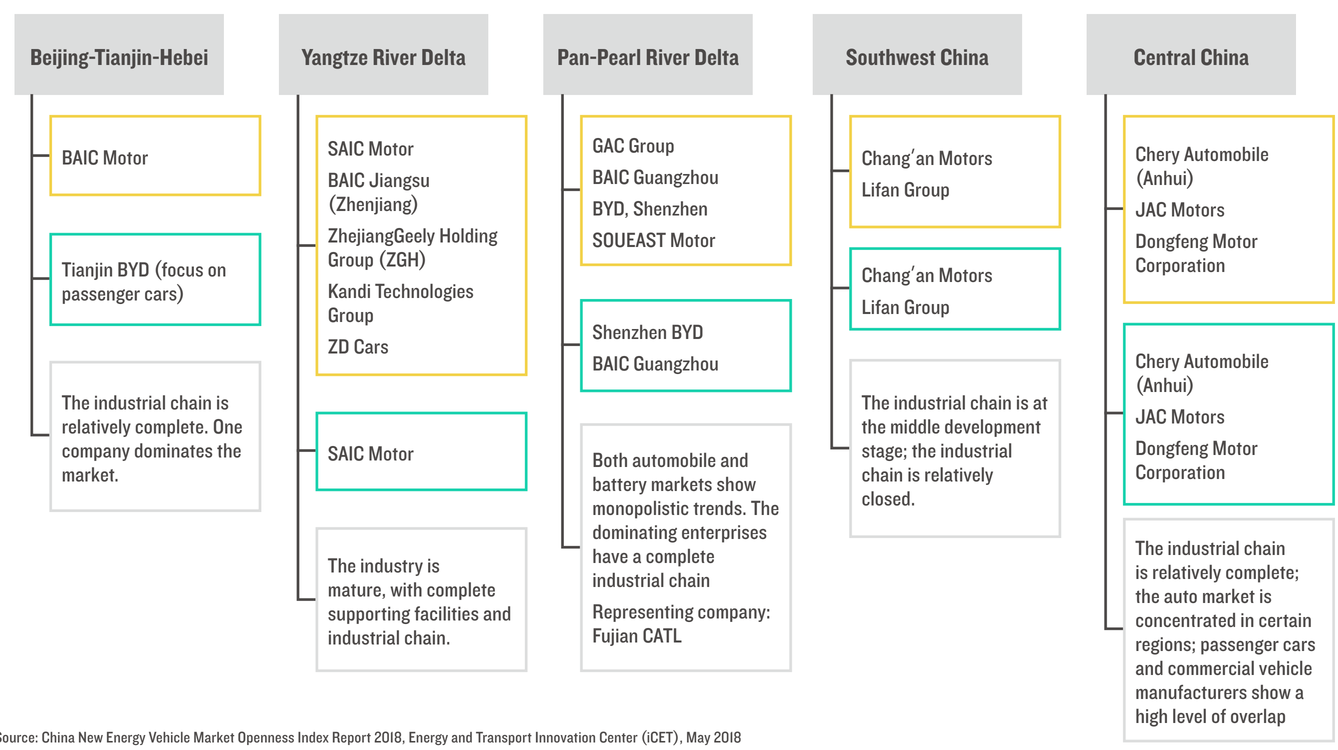
After some European countries proposed timetables for a ban on the sale of ICE-vehicles, some regions in China also took the lead in proposing a timetable for a ban (or phase-out), taking into account local development and other constraining conditions. In the *Guidelines on Supporting Hainan to Deepen Reform and Opening Up*, the State Council proposed that Hainan Island should gradually ban sales of traditional ICE vehicles. In March 2019, the Hainan Provincial Government officially issued the *Hainan Clean Energy Vehicle Development Plan* during the National People's Congress. The plan clearly stated that by 2030, the whole province will ban the sale of traditional ICE vehicles, and will strive to achieve the international benchmark level for clean energy.

Excepting vehicles with a special purpose, the province's public service and social operation vehicles will fully rely on NEVs. In the private sector, all the newly added or replaced cars will be NEVs. This is a clear signal that encourages local planning for the electrification of transportation in the region. Prior to this, many large cities already electrified public transportation to varying degrees.

On August 20, 2019, the Ministry of Industry and Information Technology (MIIT) responded positively to a proposal put forth during the second session of the 13th National People's Congress (NPC) to study and formulate a timetable for banning the sale of traditional ICE vehicles. The MIIT announced that the Ministry is working with relevant departments, including the National Development and Reform Commission, to conduct comprehensive scientific analysis of the technical costs, energy saving and emissions reduction potential, and market demand for traditional ICE vehicles and NEVs. This analysis is based on the technological development process and the realities of industrial development. Taking into account China's vast territory and unbalanced development, the Ministry will organize in-depth, detailed, and comprehensive research and analysis and will develop policies adapted to local conditions in support of local and regional pilot projects. This includes first replacing urban public transportation with NEVs and establishing non-ICEV zones. If these measures are successful, then the Ministry will develop plans for the phaseout of ICE vehicles.

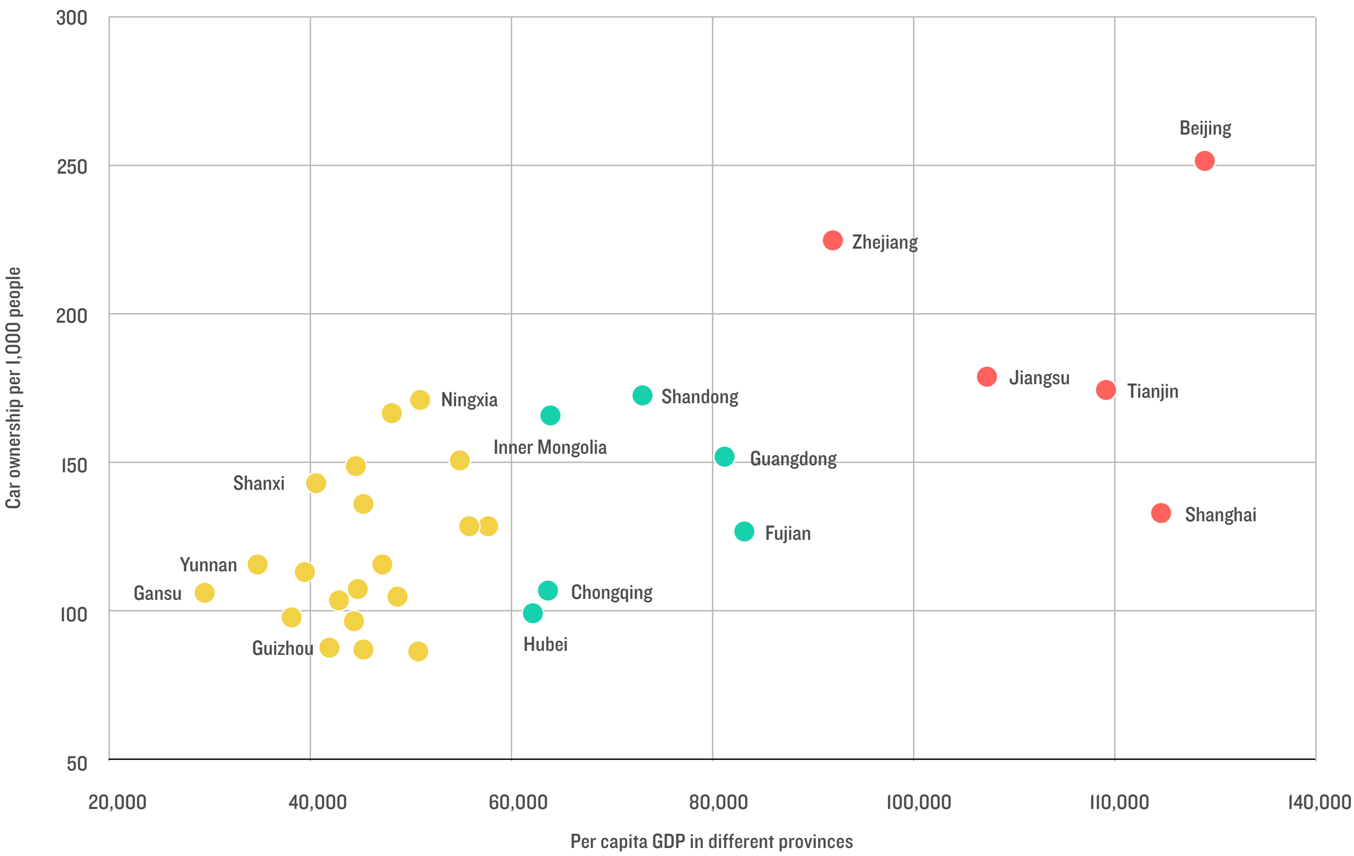
At the same time, China is actively promoting the development of NEVs. In order to encourage regional economic development, all regions are eager to provide good conditions for the development of NEVs and its upstream and downstream industrial chains (including batteries, motors, electric controls, charging stations and other automobile services, etc.) These include the establishment of NEV industrial parks, corresponding subsidies and corporate tax incentives. Especially since 2009, the country began to implement the NEV city promotion demonstration projects. The demonstration project will eventually cover 88 cities and regions. Industrial clusters are forming in many regions, making the NEV industry the main driver of economic development in some regions. As shown in Figure 7.1.

FIGURE 7.1: AN OVERVIEW OF MAJOR NEV INDUSTRY CLUSTERS IN CHINA



Source: China New Energy Vehicle Market Openness Index Report 2018, Energy and Transport Innovation Center (iCET), May 2018

FIGURE 7.2: CAR OWNERSHIP PER 1,000 PEOPLE VS PER CAPITA GDP IN DIFFERENT PROVINCES



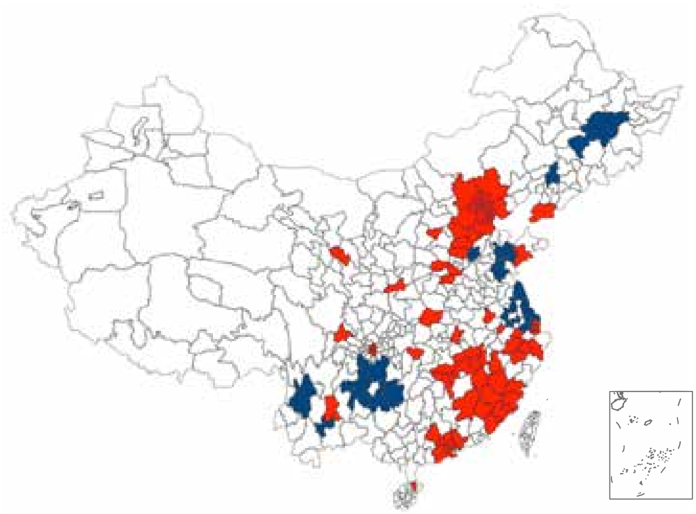
Source: China Statistical Yearbook 2018, National Bureau of Statistics, China Statistics Press, October 2018.

2. REGIONAL DIFFERENCES IN OIL CONSUMPTION ARE THE BASIS FOR POLICYMAKING

China's 31 provincial-level administrative regions all have very different characteristics in terms of economic and social development and energy demand. From the perspective of oil consumption, the eastern region is the main oil consuming region in China. It is responsible for about 60% of national oil consumption. There are two major drivers contributing to oil consumption in the eastern region. Firstly, the rate of motor vehicle ownership in the eastern region is relatively large. Secondly, the eastern region has a strong industry capacity, a high petrochemical plant concentration, and a relatively long industrial chain. Therefore, the transportation and industry sectors consume relatively large quantities of oil.

From the perspective of vehicle ownership, the number of vehicles per 1,000 people in each province in China is between 80-250, as shown in Figure 7.2. In the eastern region, the number of vehicles per 1,000 people is 1.56 times and 1.46 times the average value of the central and western regions. From the perspective of future development, the number of vehicles in the eastern region is already close to saturated, and some large and mega-cities have adopted measures such as restricting traffic and purchases in order to improve air quality and to ease traffic congestion. The growth rate of oil demand in the transportation sector will slow down and will eventually start to decline in these cities. It goes without saying that local oil cap plans in the transportation sector also require division into different districts and require implementation at different time periods.

FIGURE 7.3: DEMONSTRATION CITIES FOR PROMOTING NEVS IN CHINA



Note: red shows the first batch of demonstration cities (November, 2013); blue shows the second batch (January 2014)

Source: A Study on China's Timetable for Phasing-out Traditional ICE-Vehicles; Energy and transportation Innovation Center (iCET), China Oil Consumption Cap Plan and Policy Research Project, May 2019

TABLE 7.1: AN OVERVIEW OF NEV INCENTIVE POLICIES IN CHINESE CITIES

	POLICY MEASURES	BEIJING	SHANGHAI	SHENZHEN	TIANJIN	HAIKOU	QINGDAO	CHENGDU	HANGZHOU	GUANGZHOU	CHANGSHA	ZHENZHOU	WUHAN	CHONGQING
Economic measures	Local subsidy for purchasing BEVs	●	●	●	●	●	●	●	●	●	●	●	●	●
	Local subsidy for purchasing PHEVs		●	●	●	●	●	●	●	●	●	●	●	●
	Vehicle and boat tax reduction	●	●	●	●	●	●	●	●	●	●	●	●	●
	Parking fee reduction			●	●			●						
	Charging discount	●	●	●	●				●				●	
	Subsidy for upgrading car to NEV													
	Compulsory auto insurance fee reduction													
	Private charging station subsidy			●	●									
	License plate fee discount	●	●	●	●				●	●				
	Toll reduction			●	●								●	●
Administrative measures	Subsidy for charging station construction		●	●	●			●	●	●		●	●	●
	Restrictions on purchasing ICE vehicles	●	●	●	●	●			●	●				
	Traffic restrictions for ICE vehicles	●	●	●				●	●	●		●	●	
	Exemptions for NEVs	●	●	●	●	●	●	●	●	●	●	●	●	●

Source: A Study on China's Timetable for Phasing-out Traditional ICE-Vehicles, Innovation Center for Energy and Transportation (iCET), China Oil Consumption Cap Plan and Policy Research Project, May 2019

3. ACTIVELY PROMOTING THE ELECTRIFICATION OF URBAN TRANSPORTATION

In 2009, China kicked off the "Ten Cities and Thousand Vehicles" project and began to promote NEVs. At present, 88 cities and regions have been designated as demonstration areas for the promotion of NEVs, as shown in Figure 7.3. In order to support the development of NEVs, various regions have introduced a series of incentive mechanisms for NEVs, including monetary policies such as local subsidies, charging subsidies, and parking fee reductions. Non-monetary policies include exemption for NEVs from traffic or purchase restrictions etc. For a summary of these incentive policies in different demonstration cities see Table 7.1. The demonstration cities adopted and implemented comprehensive measures and programs, leading to a more effective demonstration role and faster development.

Most cities propose the use of NEVs in sectors such as public transportation, sanitation, postal services, express delivery, taxi and network leasing. Government institutes and state-owned enterprises should take the lead in promoting the use of NEVs. Some cities and regions have defined their own targets and implementation pathways. For example, Shenzhen fully electrified its public transportation and taxis by 2018. Shenzhen also committed to all new light-duty trucks being battery electric vehicles and to providing priority road rights for BEV logistic vehicles. It also committed to the full electrification of rental cars and app-based ride-sharing cars by the end of 2020.

Beijing is also requiring the electrification of public transportation for key routes, all rapid transit systems (BRT), and connection loops to new urban areas, as well as airport express routes. All new taxis are required to be NEVs, and existing taxis should be upgraded to

SHIJIAZHUANG	NANJING	HEFEI	TAIYUAN	XI'AN	NANCHANG	KUNMING	WUHU	LANZHOU	XIAMEN	LINYI	XIANGTAN	ZHUZHOU	HUZHOU	YICHUN	NINGBO	NANTONG
●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
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electric vehicles in an orderly manner. Taxis in all of the 10 suburban areas should be NEVs, and the proportion of new NEVs used in the sanitation sector must exceed 50%. In 2016, Taiyuan city completely electrified its taxi fleet. From May 2018 onwards, Xi'an will also no longer add non-electric buses and vehicles for factory commuting, for sanitation, and for house moving, logistics and others.

The China Oil Cap Project carried out NEV case studies and demonstration projects in cities including Guangzhou, Hangzhou, Tianjin, Jinan and Yichang. The project's aim is to sum up the best practices for urban EV development and then to promote these practices in various regions to accumulate more experience from local pilots.

4. FORMULATING ICE VEHICLES PHASE-OUT TIMETABLES BY REGION, CAR TYPE, AND PHASE

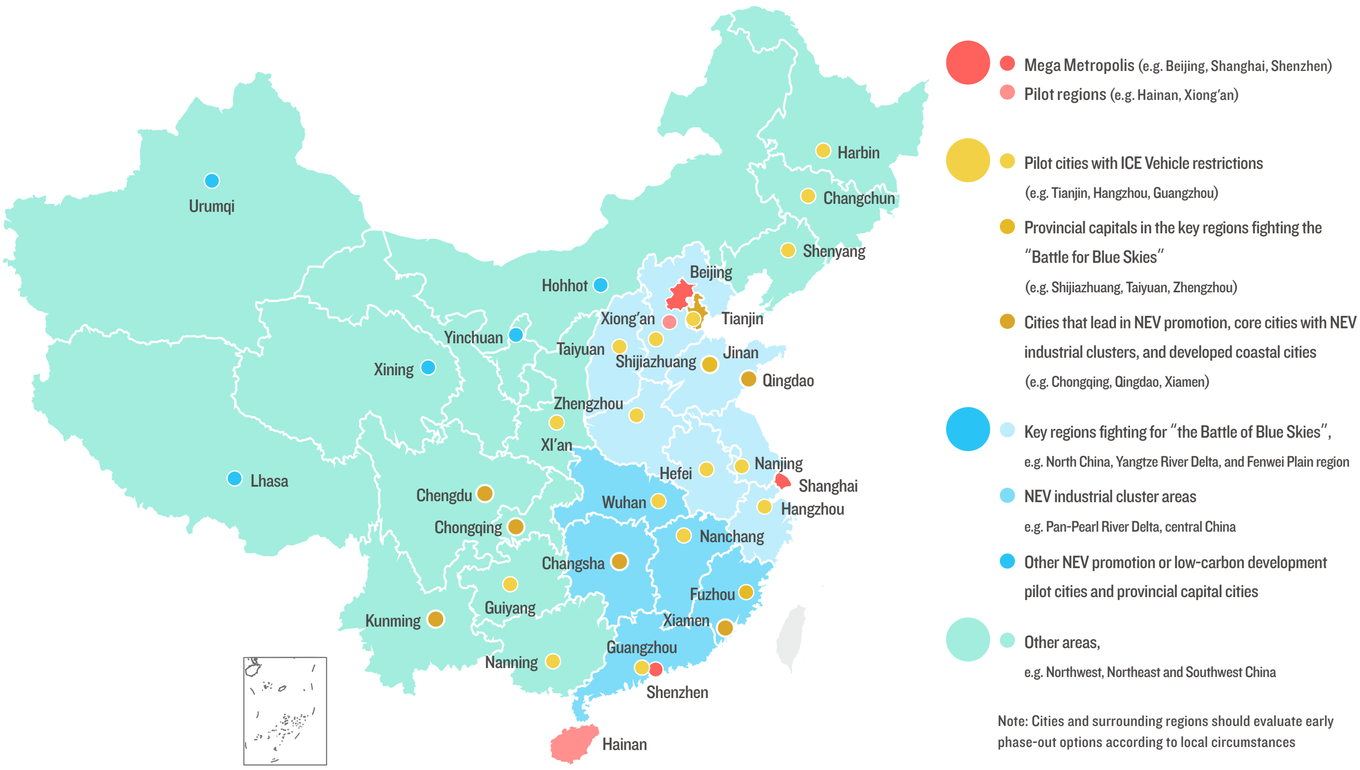
This report proposes a sales ban or phase-out timetable for traditional ICE vehicles by different regions, car types and phases. Car ownership is still growing in China. The difficulties of phasing out different types of traditional ICE vehicles is highly affected by the changes in costs and technologies. With complex vehicle structure and application scenarios, China needs to come up with a timetable to phase-out ICE vehicles by region, car type, and phase. In terms of regions, mega-cities and certain provincial capital cities should take the lead in capping car ownership and phasing-out ICE vehicles. Further transition can be expanded to areas with a developed economy, mature automobile industry and serious pollution. Finally, it can be expanded to economically underdeveloped areas with backward automobile industries. In underdeveloped regions and in rural areas it is encouraged to market small, low-speed, low-cost electric vehicles, and at the same time to promote the implementation of relevant safety standards. In terms of car types, ICE vehicles in the public sector should be phased-out first, including public buses, taxis, vehicles for sanitation, postal and logistic services etc. These will be

TABLE 7.2: DIVISION OF REGIONS AND REPRESENTATIVE AREAS FOR THE TRADITIONAL ICE VEHICLE PHASE-OUT PLAN

LEVEL	MAIN REPRESENTATIVE REGIONS
Phase I	• Mega Metropolis (e.g. Beijing, Shanghai, Shenzhen) • Pilot regions (e.g. Hainan, Xiong'an)
Phase II	• Pilot cities with ICE Vehicle restrictions (e.g. Tianjin, Hangzhou, Guangzhou) • Provincial capitals in the key regions fighting the "Battle for Blue Skies" (e.g. Shijiazhuang, Taiyuan, Zhengzhou, Jinan, Xi'an, Nanjing, Hefei, Fuzhou, Nanchang, Nanning, Chengdu, Changsha, Kunming) • Cities that lead in NEV promotion, core cities with NEV industrial clusters, and developed coastal cities (e.g. Chongqing, Qingdao, Xiamen, Shenyang, Changchun, Harbin, etc.)
Phase III	• Key regions fighting for "the Battle of Blue Skies", e.g. North China (Hebei, Henan, Shandong), Yangtze River Delta (Jiangsu, Zhejiang, Anhui), and Fenwei Plain region (Shanxi, Henan, Shaanxi) • NEV industrial cluster areas e.g. Pan-Pearl River Delta (Guangdong, Hong Kong and Macao), central China (Hunan, Hubei, Jiangxi) • Other NEV promotion or low-carbon development pilot cities and provincial capital cities • Northeast China (Heilongjiang, Liaoning, Jilin)
Phase IV	• Other regions: northwest China (Xinjiang, Tibet, Ningxia, Gansu, Shaanxi, Qinghai), southwest China (Guangxi, Yunnan, Guizhou, Sichuan), Inner Mongolia

Source: A Study on China's Timetable for Phasing-out Traditional ICE-Vehicles, Energy and Transportation Innovation Center (iCET), China Oil Consumption Cap Plan and Policy Research Project, May 2019

FIGURE 7.4: DIVISION OF REGIONS FOR THE TRADITIONAL ICE VEHICLE PHASE-OUT PLAN



Source: A Study on China's Timetable for Phasing-out Traditional ICE-Vehicles, Energy and Transportation Innovation Center (iCET), China Oil Consumption Cap Plan and Policy Research Project, May 2019

followed by private cars with higher technological maturity and lower costs. The phase-out of medium- and heavy-duty vehicles should be implemented when the technology is mature and production costs are competitive.

As shown in Table 7.2 and figures 7.4 and 7.5, mainland China can be divided into four categories by region taking account various indicators, including economic indicators (e.g. per capita), vehicle saturation (e.g. car ownership per 1,000 people and purchase restrictions), NEV development (e.g. NEV sales and development planning), and the development of charging infrastructure (e.g. the number of public charging stations).Other indicators such as the openness of the region, and the carbon intensity of electricity in various regions are also considered.

We recommend the formulation of a phase-out timetable and roadmap for traditional ICE vehicles with different priority levels based on the characteristics of different vehicle types, as shown in Figure 7.5. In the process of replacing ICE vehicles, passenger cars can be categorized into two priority levels, PV1 and PV2. PV1-a includes taxis, app-based shared car, etc. PV1-b includes service vehicles used by state-owned enterprises and institutions. PV2 mainly refers to private cars. Commercial vehicles can be divided into three priority levels: CV1 mainly includes urban public buses, sanitation, light logistics, commuting and port and airport transportation vehicles, etc.; CV2 mainly includes other medium and light vehicles for special purposes, medium-sized logistic vehicles and ordinary buses; CV3 mainly includes medium and heavy duty trucks, etc.

The phase-out plan for traditional ICE vehicles by region, by car type, and by stage can be seen from Table 7.2 and Figure 7.5. Taking account of the NEV development strategies tailor-made for auto companies, a comprehensive traditional ICE vehicle phase-out timetable is clear and feasible. The

FIGURE 7.5: TIMETABLE FOR PHASING OUT ICE VEHICLES BY CAR TYPES

	Passenger Cars PVI-a	Passenger Cars PVI-b	Passenger Cars PV2	Commercial vehicles CVI	Commercial vehicles CV2	Commercial vehicles CV3
2020	I. II			I. II		
2025	III	I. II		III		
2030	IV	III. IV	I. II	IV	I	
2035			III		II	I
2040			IV		III	II
2045					IV	III
2050						IV

Note 1: PVI-a includes taxis, app-based rental and shared-riding cars, etc.; PVI-b includes state-owned service vehicles; PV2 mainly refers to private cars. CVI mainly includes urban public buses, sanitation, light logistics, commuting, port and airport transportation vehicles, etc.; CV2 mainly includes ordinary buses, inter-city logistic vehicles and vehicles for special purposes; CV3 mainly includes medium- and heavy-duty trucks, etc.

Note 2: I, II, III, IV stand for the regions per phase-out phases as mentioned in Table 7.2

Source: A Study on China's Timetable for Phasing-out Traditional ICE-Vehicles, Energy and Transportation Innovation Center (iCET), China Oil Consumption Cap Plan and Policy Research Project, May 2019

suggested timetable provides useful reference for the MIIT to formulate a policy plan for "the ban/phase-out of ICE vehicles" in the future.

5. CASE STUDY: OIL CONSUMPTION PEAK AND CAP IN THE CITY OF HANGZHOU

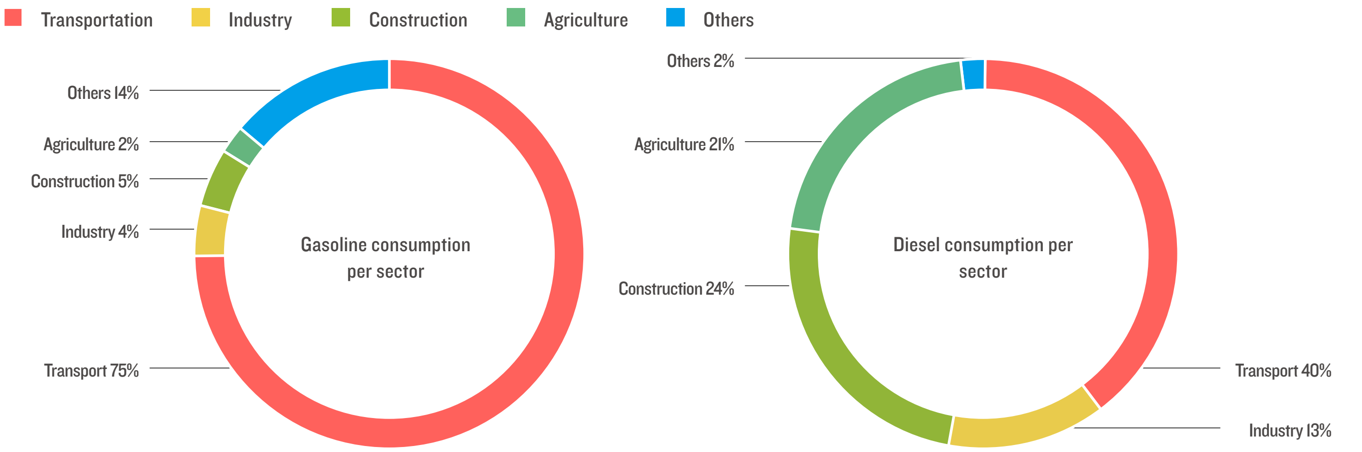
Hangzhou is an internationally renowned city in China and a national leader in green development. Together with its economic growth and the growth of car ownership, Hangzhou is facing the so called "urban disease" with symptoms such as severe vehicle exhaust emissions, traffic congestion and other environmental constraints. Studies have shown that through developing public transportation, reducing car use, promoting "green" transportation options, optimizing traffic and oil use efficiency, oil consumption in Hangzhou's transportation sector is expected to peak by 2022. This means that Hangzhou would be among the first league of cities in China to peak carbon emissions. Its pioneering experience in capping and peaking oil consumption provides an important reference for other economically developed cities as well as for the national oil peak and cap plan.

5.1 Oil consumption in Hangzhou's transportation sector: background and present situation

Transportation is the primary sector in terms of refined oil consumption. According to data from the Hangzhou Municipal Bureau of Statistics, in 2017 Hangzhou's oil consumption was about 4.69 million tons, accounting for 17.3% of the total energy consumption. Specifically, gasoline accounted for 1.9 million tons and diesel accounted for 1.5 million tons of oil consumption. In terms of gasoline and diesel consumption division by sector, the industrial sector accounts for 4% and 13% respectively, and the transportation sector accounts for 75% and 40%. For other sectors such as the agriculture and service sectors (excluding transportation), see Figure 7.6.

Hangzhou's number of motor vehicles has grown rapidly. Statistics show that in 2017, the number of citizens owning motor vehicles (excluding motorcycles/bikes) in Hangzhou reached 2.431 million, of which 1.99 million are private cars, accounting for 82% of the total. From 2006 to 2013, the number of motor vehicles increased rapidly, and the average annual growth rate reached 19%. Starting from 2014, Hangzhou has

FIGURE 7.6: CONSUMPTION STRUCTURE OF DIESEL AND GASOLINE IN HANGZHOU (2017)



Source: The Carbon Reduction Pathways for the City of Hangzhou under an Oil Cap Scenario, Zhejiang Cooperation Center for Climate Change and Low Carbon Development, China Oil Consumption Cap Plan and Policy Research Project, June 2019.

implemented a policy that limits the number of passenger cars. This resulted in the growth rate of motor vehicles slowing down significantly, with the average annual growth rate dropping to 4.6%. In 2018, the number of private cars in Hangzhou was 2.078 million, and the number of cars per 1,000 citizens was 259, about twice the national average. Compared to other major cities, Hangzhou is at the forefront of capping oil consumption.

The cargo transportation turnover rate continues to rise. In 2012-2017, Hangzhou's freight turnover increased by 16%, with an average annual growth rate of about 3%. Specifically, road freight transportation developed rapidly, and the road freight turnover in 2017 increased by 12.3% compared to the previous year. In the context of accelerated development of the e-commerce and distribution industries, the volume of express delivery has also grown rapidly, from 260 million in 2012 to 2.32 billion in 2017, with an average annual growth rate of 55.6%.

Urban traffic congestion is getting worse. In 2016, Hangzhou ranked 8th among the nation's most congested cities, and traffic congestion was severe[55]. In recent years, the traffic congestion situation in Hangzhou has improved and the average speed during peak traffic increased to 25 km/h, but the peak congestion delay index is still as high as 1.648, which means that about 40% of the time one encounters traffic congestion. It can be concluded that the overall traffic efficiency is not satisfactory[56].

The transportation sector's oil consumption is an important source of air pollution. In 2013, there were 239 "smoggy" days including 5 periods with large-scale severe smoggy weather. Since 2014, the air quality in Hangzhou has continued to improve and the number of days with polluted weather has decreased. However, there were still about 100 days of hazy weather throughout the year in 2018. According to data from the Hangzhou Environmental Protection Bureau, the transportation sector is the "main culprit" of air pollution. About 28% of $PM_{2.5}$ comes from motor vehicle emissions.

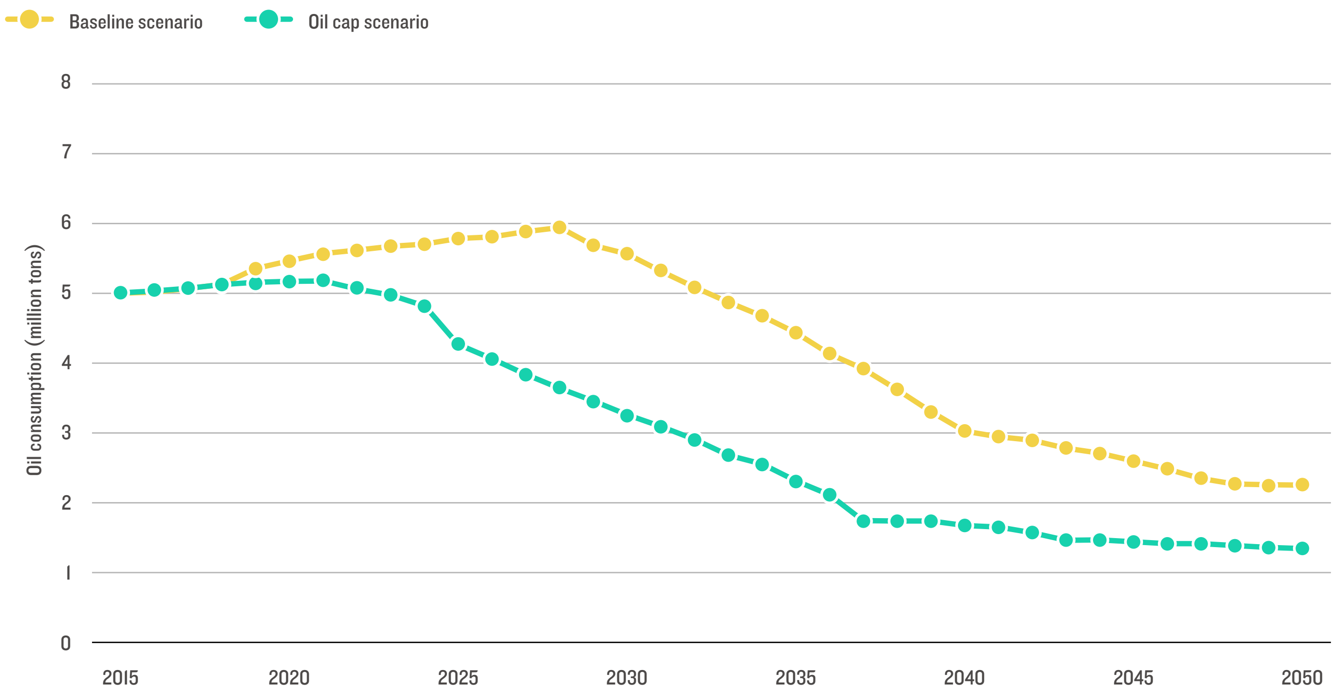
5.2 Analysis of the overall oil consumption scenario in Hangzhou

The Hangzhou Oil Cap Research proposed a baseline scenario and an oil cap scenario. Under the baseline scenario, the existing policies in Hangzhou remain unchanged. Under the oil cap scenario, the total consumption of oil products such as gasoline and diesel will be further constrained and the

[55] "2016 China Major City Traffic Analysis Report", Gaode Map, January 2017

[56] "Q2 China Major City Traffic Analysis Report, 2018", Gaode Map, September 2018

FIGURE 7.7: OIL CONSUMPTION SCENARIOS IN HANGZHOU



Source: The Carbon Reduction Pathways for the City of Hangzhou under an Oil Cap Scenario, Zhejiang Cooperation Center for Climate Change and Low Carbon Development, China Oil Consumption Cap Plan and Policy Research Project, June 2019.

application of new technologies in the transportation sector will be promoted. In addition, the development of the non-motorized transportation and shared transportation will further speed up. Compared with the baseline scenario, in the oil cap scenario, Hangzhou's oil consumption will be further reduced. In 2050, Hangzhou's oil consumption is expected to reach 1.25 million tons, about 80% less than 2017. Furthermore, the proportion of oil consumption in total primary energy consumption is expected to fall from 19% in 2017 to 4% in 2050, as shown in Figure 7.7.

5.3 Policy measures to further control urban traffic oil consumption

Under the oil cap scenario, the oil consumption of Hangzhou's transportation sector is expected to reach its peak around 2022. Hangzhou will further clarify the oil consumption cap pathway and strengthen the efficient use of petroleum to reduce consumption. It will also take the lead in promoting urban energy reform and in achieving peak CO_2 emissions. In the field of urban transportation, the report focuses on the four major paths of "reduction", "transformation", "enhancement" and "optimization" to ensure oil consumption peak.

"Reduction" refers to reducing travel demand and distance traveled by motor vehicles. The report suggests that the land use plan should coordinate with transportation demand. Relying on transportation facilities such as railways and compact use of land should be encouraged along the traffic corridor with mixed functions to achieve a balance between residential areas and transportation corridors. The city should promote the transit orientated development (TOD) model for land use. This model drives comprehensive planning of and rail transit stations in accordance with other urban functions such as businesses, offices and cultural and residential centers, and accelerates the intensive use of land in urban hub areas.

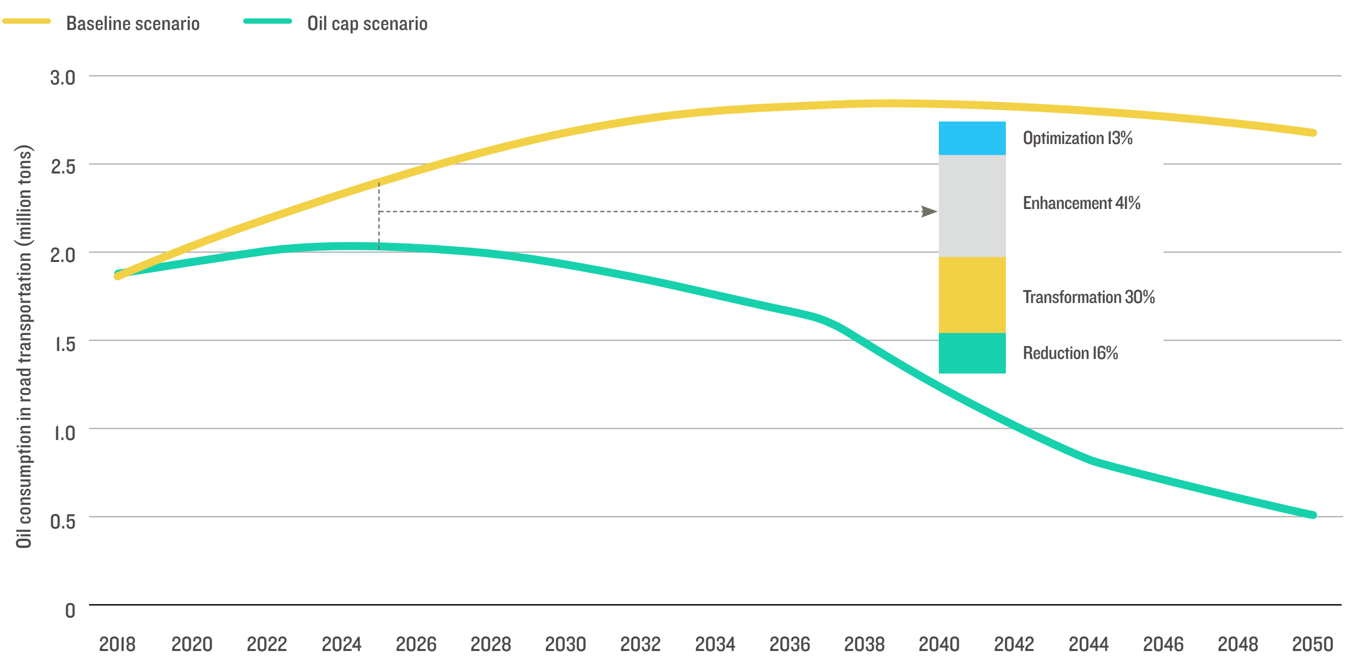
"Transformation" refers to shifting modes of transportation. The report suggests that Hangzhou should promote the development of bus rapid transit (BRT) and bus lanes in order to effectively maintain space and 'right of way' for public transportation. In addition, providing efficient and convenient public transportation services requires further integration of bus and rail systems and structural optimization of the bus line network. Priority will be given to the use of public transportation, walking and bicycle lanes. The width of sidewalks and the setting of bicycle lanes will be adjusted, and road use will be switched from a small bus dominated mode to public plus non-motorized transportation dominated mode. It is recommended to set up low-emission zones (LEZ) around the West Lake Scenic Area and the city center, encouraging tour buses and public buses to be replaced with NEVs, and strictly limiting the access of small ICE vehicles to the scenic spots.

"Enhancement" refers to improving the fuel economy of motor vehicles and the proportion of alternative energy vehicles. This report proposes speeding up the replacement of traditional ICE vehicles with NEVs in Hangzhou. Public buses, taxis, postal vehicles, sanitation vehicles and government vehicles should be replaced with NEVs first, followed by app-based ride-sharing cars, logistic vehicles, tourist buses and water taxis. It is also suggested to explore the formulation of a timetable for phasing out traditional ICE vehicles in Hangzhou by strategic implementation by sectors and car types.

"Optimization" refers to optimizing intelligent management of transportation. Firstly, the report proposes improving the sensory and transmission systems of roads, vehicles, transfer stations, parking lots, etc. Secondly, it proposes establishing traffic awareness systems including traffic monitoring, signal sensing, and license plate recognition based on urban digital maps to realize networked, digitized and visualized traffic information. Governments can rely on urban big data to promote the application of intelligent technologies such as online real-time accessibility of resources on infrastructure, transportation tools, and operational information. Lastly, it is recommended to improve the multi-level and integrated information service for public transportation, intercity and city road traffic, and widely promote the use of "Internet + Green Logistics."

Comprehensive assessment analysis shows that, compared with the baseline scenario, achieving the goal of peaking oil consumption for road traffic in 2022-2023 in Hangzhou will require different measures. The contribution of the so called "reduction" measures towards this goal is about 16%, "transformation" measures contribute about 30%, "enhancement" measures account for about 41%, and "optimization" measures contribute 13%, as shown in Figure 7.8.

FIGURE 7.8: FOUR MAJOR PATHWAYS TO ACHIEVE PEAK OIL CONSUMPTION OF ROAD TRAFFIC IN HANGZHOU



Source: The Carbon Reduction Pathways for the City of Hangzhou under an Oil Cap Scenario, Zhejiang Cooperation Center for Climate Change and Low Carbon Development, China Oil Consumption Cap Plan and Policy Research Project, June 2019.

8

SAFEGUARD MEASURES OF AN OIL PEAK AND CAP

Measures for achieving a peak and cap on oil consumption should focus on safeguarding the strategic goal of "Leaping over the Age of Oil". Firstly, China should accelerate establishing the true costs and market prices that reflect the external costs of oil. Secondly, institutional reforms should be intensified in the areas of finance, taxation, investment and management to form a market environment conducive to promoting increased efficiency, reductions in demand, replacement with other fuel sources, optimization and the clean utilization of oil. In addition, China should promote unconventional oil and gas extraction and should support an automobile technology revolution, giving impetus to green, low-carbon, quality-oriented economic development.

I. ADOPT KEY MEASURES SUGGESTED BY THE CHINA OIL CAP PROJECT

The China Oil Cap Project hopes that relevant government departments can adopt and formulate related policies and measures to reach the oil cap pathway targets: peak oil consumption by 2025; realizing the vision of a "Beautiful China" by 2035; and meeting the 'carbon neutral' requirements of the 1.5°C temperature control target by 2050.

Firstly, we recommend the formulation of a timetable and roadmap for the phase-out of traditional ICE-vehicles. The transportation sector is facing huge changes in its energy structure and a revolution in the traditional automotive industry. It is necessary to fully embrace the initiatives of local governments and enterprises, encourage the formulation of local ICE vehicle phase-out timetables and specific implementation roadmaps, and encourage car companies to set their own goals and strategies for the development of NEVs. Based on the practices of local companies and car industries, policy makers can introduce timely phase-out timetables and roadmaps for ICE vehicles. By doing so, they are sending a clear signal to investors, leading the way for technological innovation. They are also sending a signal to the automobile sector that it should be setting aside space for strategic adjustments and must provide consumers with a more a sustainable option.

Secondly, we recommend the development and implementation of an updated "Restriction on Plastics" that prohibits, restricts, replaces and recycles the production and use of petroleum-based plastics from the source. China is the biggest consumers of plastics in the world, causing great damage to the environment. The chemical industry need to do a better job in terms of prohibiting, limiting and replacing plastics, further accompanied by recycling, re-use and clean disposal. Establishing a "platform for clean use of plastics", combined with waste sorting and the so-called 'zero-waste cities' campaign, can push the "clean use of plastics" initiative to a new level.

Thirdly, in other sectors it is recommended to establish and implement higher energy efficiency and emissions standards for a wide range of fuel-consuming equipment. In addition, attention must be paid to the energy consumption standards and emission standards of gasoline and diesel engines.

Lastly, we recommend a China Oil Cap for the "14th Five-Year Plan". We propose to raising the "dual-credit scheme" for passenger cars to a national binding target, setting the proportion of oil in total energy consumption as a guiding indicator, and using China's dependence on crude oil imports as an 'early warning' indicator.

2. PROMOTE THE INTERNALIZATION OF THE EXTERNAL COSTS OF OIL DEVELOPMENT AND UTILIZATION

The environmental costs of oil, as an important part of the external costs of fossil energy, should be internalized in its actual price. China's resource and environmental finance and taxation system is still imperfect, resource prices are low, and external costs have not yet been fully internalized, resulting in low efficiency and the wasteful use of fossil energy.

Based on international comparison, it can be concluded that the tax burden of China's refined oil consumption is higher than that of low-tax countries such as the United States, but it is generally lower than tax burden levels in the EU and Japan. China's energy security and environmental pollution are becoming more and more serious, and the related external costs will likewise increase. It is necessary to further promote reform of the resource and environmental taxation system and accelerate the internalization of the external costs of oil extraction use and development

Lastly, we recommend choosing the right time window to promote the reform of the oil fiscal and taxation system according to the principle of "tax neutrality". Oil prices can significantly affect the costs of logistics, petrochemical products, and residents' travel. It is recommended to choose an opportunity window period to carry out adjustments in order to maintain a moderately stable price for refined oil and to avoid the social upheaval caused by an increase in the refined oil consumption tax. At this period of low international oil prices, it is possible to increase the oil resource tax and the refined oil consumption tax, and clearly specify the use of the tax after payment. On the other hand, there are a large number of other taxes and fees in China's transportation sector, such as tolls, bridge fees, the vehicle purchase tax, etc. Therefore, while increasing resource taxes and consumption taxes, other taxes and fees could be reduced or eliminated, so as to maintain "tax neutrality" and to avoid any negative impact on social and economic development.

3. SPEED UP THE ADJUSTMENT AND REMOVAL OF UNREASONABLE OIL SUBSIDIES

We recommend speeding up the adjustment and removal of unreasonable oil subsidies, restoring the commodity attributes of oil. The adjustment should be centered around improving energy efficiency, combining multi-faceted and multi-disciplinary promotion with the reform of China's energy pricing mechanism and taxation system. This reform should focus on standardizing fossil energy subsidies and gradually removing inefficient fossil energy subsidies. In terms of implementation, it is recommended to reduce fossil energy subsidies in different areas step by step and in phases based on their content, nature, rationality, and connection with other policies.

In the near future, we recommend adjusting the consumption tax rebate policy for the oil products used in crude oil mining and the exemption of the consumption tax for self-produced refined oil products used during oil refinery. Our medium and long-term recommendations include abolishing: (1) preferential policies on urban land use including taxes for the mining and production of fossil fuel; (2) the 13% preferential value added tax (VAT) rate for some fossil fuel consumption, such as gas; (3) exemptions for heating companies from VAT, property tax, urban land use tax and other preferential policies. In addition, subsidy policies, along with oil product price and tax reform need to be adjusted.

Additionally, we recommend pushing forward the reform of market-oriented pricing mechanisms for refined oil products and the adjustment of subsidy policies. In the short term, the key will be to improve the specific measures for "pricing linkage" between domestic refined oil prices and international crude oil prices, further shortening or liberalizing restrictions on the pricing and price adjustment cycle of refined oil products, and gradually eliminating certain special price regulations. In the mid-long term, with the complete reform of the entire refined oil production and distribution system, the goal of adjusting the transaction price in real time according to market regulations should be gradually realized[57].

[57] Fiscal and Tax Policies for Capping China's Oil Consumption, China Academy of Fiscal Science, China Oil Consumption Cap Plan and Policy Research Project, June 2019

4. IMPROVE FISCAL AND TAXATION POLICIES THAT PROMOTE CONSERVATION AND OIL SUBSTITUTION

China's oil consumption structure has great potential for conservation and substitution. Fiscal and tax policies should play an effective role in regulating and guiding this process. Long term development goals include automobile electrification, network integration, the development of intelligent systems and vehicle sharing. In the short term, however, China's consumption of new automobiles is mainly in third- and fourth-tier cities and rural areas. Therefore, we should focus on improving energy efficiency as well as promoting NEVs in these areas. Additionally, the government should provide preferential tax policies as well as certain subsidies in order to promote the purchase of energy efficient low-emission vehicles and NEVs.

4.1 IMPROVE SUPPORTIVE FISCAL AND TAXATION POLICIES FOR ENERGY-EFFICIENT VEHICLES AND NEVS

Improve long-term stable fiscal and taxation policies that support the development of energy-efficient vehicles and NEVs. As subsidies for NEVs are gradually declining, it is recommended to implement stricter EV admission criteria and higher energy efficiency standards for ICE vehicles taking account of the industrialization and technological progress of NEVs. The report suggests extending the exemption period for the automobile consumption tax and vehicle purchase tax for the energy-efficient vehicles and NEVs meeting the new criteria to provide long-term stable tax policies for automobile manufacturers and consumers. This report also recommends the introduction of an income tax deduction policy for enterprises and individuals purchasing energy-efficient vehicles and NEVs.

Increase financial support for NEV technology R&D and for the infrastructure construction. We propose improving the mechanism by which financial subsidies are reduced and adjusted, further raising the subsidy threshold, supporting the steady growth of the NEV market, and encouraging competitive enterprises to become bigger and stronger. In addition, it is recommended to gradually adjust the direction of fiscal subsidies through increasing financial support for independent R&D and innovation, promoting industry-university research cooperation and R&D of key technologies. In areas such as public charging facilities and power transmission and distribution networks, we suggest leveraging public financing to attract investment from automotive companies and social capital on the infrastructure, combining with innovative investment and operation models.

Improve government's procurement policy for NEVs. Government procurement is one of the most important policy instruments for promoting NEVs. At present, China's procurement of NEVs is mainly in the fields of public transportation, logistics, rentals, sanitation and official service vehicles. It is recommended that, based on the current government procurement system for environmental labeling products, the government procurement catalogue of NEVs should be reasonably redefined, to encourage the public sector to purchase or rent more NEVs. At the same time, in combination with public vehicle reform and other policies, government agencies, state-owned enterprises and institutions should explore more flexible models for NEV rental and procurement such as renting-by-hour and vehicle sharing modes, thus enhancing the effectiveness of these policies.

4.2 IMPROVE FISCAL AND TAXATION POLICIES THAT PROMOTE OIL CONSERVATION AND SUBSTITUTION

Improve the fiscal and taxation policies that promote oil conservation and efficiency. It is recommended to improve energy conservation incentives and oil constraining policies by supporting the petroleum industry as it optimizes energy use processes, selects high-efficiency energy-saving equipment and effectively strengthens energy conservation management. We encourage the oil extraction sector to take measures such as increasing associated gas reinjection, improving oil and gas mixed transportation technology, and using associated gas condensate recovery technology with the overall goal of reinforcing the use of recovered petroleum associated gas and improving the crude oil commodity rate. This report also recommends the implementation of energy efficiency improvement plans for key energy-consuming equipment such as internal combustion engines and boilers. It is also suggested to promote energy efficiency improvements for terminal fuel products, benchmark the energy efficiency standards of key energy-consuming industries, and encourage the oil industry to make full use of waste heat and pressure in companies and industrial zones.

Increase financial and tax support for comprehensive energy-saving transportation systems. We suggest improving fiscal and tax support policies to speed up the phase-out of inefficient vehicles and ships, promote the development of green logistics such as multimodal transportation, swap body transportation and shared logistic services, and encourage of "internet plus" model to improve the efficiency of transportation system. In addition, encouraging the use of "internet plus" would improve the efficiency of the transportation system. It is also recommended to increase fiscal and taxation support of the public transportation system, making urban public transport an important part of a city's basic public services, including it in the scope of public financial support and continuously increasing the investments. Lastly, we recommend that current preferential policies for public transportation, such as the public transport value-added tax, vehicle purchase tax, vehicle and vessel tax and urban land use tax, be adopted as long-term preferential policies.

Improve fiscal and taxation policies that promote oil substitution. The use of NEVs in urban public transportation and other fields should be popularized, the use of liquefied natural gas (LNG) in long-distance cargo and water transportation should be promoted, and fiscal and tax incentives for the purchase of NEVS and the construction of NEV infrastructure including charging stations should be adopted. Fiscal and tax support for bioethanol fuel and biodiesel should also be increased. Under the premise that it will not affect domestic food security and the fair disposal of aged grain, it is recommended to develop fiscal incentive and discount policies to support the R&D and promotion of advanced liquid biofuel technologies such as cellulosic fuel ethanol. This should be accompanied by increases in fiscal and tax support for biofuel ethanol and biodiesel. We also suggest that preferential VAT policies for the biodiesel industry be adjusted from a 70% retreat to 100% retreat, in order to ease the corporate burden[57].

5. COMBINE INTENSIFIED MARKET-ORIENTED REFORM OF THE RAILWAY AND PUBLIC TRANSPORTATION SECTOR WITH THE OIL CONSUMPTION CAP PLAN

To reduce oil demand growth in the transportation sector, it is necessary to build a green transportation system from the start, with railway and public transportation at its core. However, given the basic and public welfare characteristics of these industries, the overall return on investment in China's railway and public transportation sector is relatively low. Accompanied with the imperfect government subsidy mechanism and unitary corporate financing methods, the current system in turn adversely affects the sustainable investments and operations of railway and public transportation sector in China. Optimization of the transport structure and electrification of the transportation sector will also significantly reduce oil consumption.

Intensify market-oriented reform of the railway system. We recommend accelerating the opening up of the railway industry to engage in competitive business practices. This should be accompanied by improving the market entry and exit mechanisms, deepening reform of railway enterprises and passenger and cargo transportation, and accelerating the construction of a market-oriented operational mechanism in the railway industry. This would in turn be followed by the gradual liberalization of prices in competitive business areas and the gradual expansion of market pricing. Furthermore, we recommend fully opening up the railway construction market and financing the construction of new railways in different ways. It is recommended to make use of multiple methods and channels to attract investments for railway construction. We propose the release of the ownership and management rights of inter-city railways, municipal (suburban) railways, resource-developed railways and peripheral railway routes to local governments and social capital so as to encourage social capital to invest in railway construction. A Public-Private-Partnership (PPP) model could be adopted, and participation in the construction, operation and maintenance of railway projects through franchising and government procurement services should be encouraged. It is necessary to break the institutional and standard barriers for railways to connect with other modes of transportation, and to encourage the development of a multimodal transport system.

Deepen reform of public transportation systems and mechanisms. Firstly, we propose deepening cooperation on the construction and operation of public transportation, and recommend the implementation of comprehensive development policies for public transportation. It should also be ensured that the income from of land development is used for the construction and operation of urban public transport. Secondly, it is important to establish a government procurement mechanism for public transportation services, use public finance to meet the basic travel needs of the public and push urban bus companies to improve service levels through moderate competition. Thirdly, establishing cross-regional and inter-departmental coordination mechanisms would promote the integrated development of public transportation and rail transit infrastructure within urban areas and city clusters. Lastly, we recommend that public transportation enterprises carry out diversified operations by making full use of land resource potential for public transportation construction projects. This includes making use of gas stations, advertising space and other resources for capital operations to make up for the lack of funding for transportation construction[58].

6. DEEPENING INSTITUTIONAL REFORM IN OIL-RELATED SECTORS

China is currently carrying out oil and gas system reform. Making full use of the opportunities that come with reform, China is tackling the major challenges in the oil sector, including reforming the system from within and confronting its obstacles. Through the intensified institutional reform of oil-related sectors, an oil consumption peak and cap also became one of the main goals of the reform process.

Accelerate reform of the natural gas system and promote the efficient development and utilization of natural gas. At this stage, natural gas, including unconventional natural gas, has strong potential to replace oil in the transportation and petrochemical industries. However, affected by factors such as constrained resources, technology and the current system, China's domestic natural gas production is still limited. Imported gas is also not very economic, and the possibility of large-scale development is limited. The upstream market (conventional and unconventional natural gas) should be opened up, assigning the exploration blocks through competition and implementing stricter block exit mechanism. This would allow market participants who meet the entry requirements to obtain qualifications to become involved in conventional block exploration and development. Overall, it would revitalize the profitability of reserves and accelerate domestic natural gas production. In addition, the operation mechanism of natural gas pipeline network should be reformed to improve the efficiency and economy of the pipeline transmission and distribution sector and to lower the cost of natural gas. The reform includes allowing the main pipelines of major state-owned oil and gas enterprises to operate independently and improving the fair access mechanism of oil and gas pipelines. Lastly, this report recommends improving the peak regulation and reserve system for natural gas, and clarifying the responsibility and obligations of the government, gas supply enterprises, pipeline enterprises, municipal utilities and large consumers so as to increase the overall level of gas supply.

[58] "Research on the Reform of China's Petroleum Consumption Total Control System Mechanism", Institute of Economic System and Management of the National Development and Reform Commission, China Oil Consumption Cap Plan and Policy Research Project, June 2019

However, it should be kept in mind that natural gas is still a fossil fuel. China's natural gas is mainly imported, and it should only be seen as an alternative form of energy to replace coal and oil during a transitional stage. The ultimate destination of natural gas is its use as a high-quality feedstock. We need to shorten the transition phase as much as possible. The medium- and long-term focus is still to encourage traditional oil companies to increase natural gas investment, and to regard natural gas and renewable energy as the main path forward for the strategic transformation of Chinese oil companies.

Strengthen the exploration and development of domestic petroleum resources and enhance overall energy security. This report proposes deepening reform of oil and gas exploration and development management systems, increasing investment in R&D to break through the bottlenecks of unconventional oil and gas resource exploration and development technology, and to enter a large-scale development stage for deep-earth and deep-sea oil and gas resource development as soon as possible. In addition, it is imperative to further clarify the responsibilities of the central and local governments, oil companies, and major petrochemical companies. Moreover, improving the fiscal and tax incentives and compensation policies for the construction, operation and maintenance of oil reserve facilities. We should aim to establish a multi-level oil reserve system by encouraging the establishment of commercial reserves in private sectors and on local levels. The exploration, development and provision of domestic oil resources will help to gradually reverse the decline in domestic oil production in recent years, as well as to reduce dependence on imported oil and the corresponding threats it poses to China's energy security.

Improve the refined oil export policy and minimize the scale of refined oil exports. In recent years, with the continuous improvement of domestic refined oil capacity, the contradiction between supply and demand in the domestic refined oil market has become increasingly prominent, and the scale of refined oil exports has increased year by year. This is not only harmful to the energy conservation and emission reduction efforts of oil refineries, but also causes severe pollution and further increases crude oil consumption in China. Therefore, we should improve refined oil trading policies and general export policies, reduce the processing export tax rebate and general trade export quota, and effectively control the scale of refined oil exports.[58]

7. TECHNOLOGICAL INNOVATION LEADS THE DEVELOPMENT OF NEW TECHNOLOGIES

In its response to climate change, China has deemed Carbon Capture Utilization and Storage (CCUS) technology as one of the most important and cutting-edge technologies to be given priority in terms of R&D, demonstration and commercial promotion. At present, CCUS technology has made remarkable progress in increasing production in oil and gas fields. Compared with water injection and conventional water fracturing technology, the CO_2-based enhanced oil recovery (EOR) has multiple advantages such as reservoir protection, better production efficiency, water conservation and pollution reduction, and efficient CO_2 storage.

CCUS for enhanced oil and gas recovery has made great progress as shown in several demonstration projects. Different technologies are adopted for different types of oil and gas reservoirs, including CO_2 fracturing technology, CO_2 near wellbore treatment technology and CO_2 injection technology. 70% of new reserves in China are low permeability reservoirs. Unconventional oil and gas development is an area of great potential. Conventional fracturing have shown the disadvantages of large water injection, high pollution and high environmental pressure. At present, the CO_2-based EOR technology accounts for less than 2% of China's EOR services, and the potential of CCUS has attracted more and more attention. However, the CO_2 storage technology has not yet been fully developed, and China should invest more resources in R&D, demonstration and commercial promotion of this technology.

China's oil and gas development and utilization occupies a lot of land, especially in areas with sparse vegetation. In the development process, oil and gas companies should pay attention to environmental protection and should carry out vegetation restoration. This is a concrete action to mitigate and adapt to climate change and it is well worth promoting. During the development and utilization of energy, especially of oil, gas and coal, the industry will emit methane and other associated gases. The greenhouse effect of these gases is several times higher than that of carbon dioxide. The recovery and utilization of these gases therefore also has significant economic benefits. It is crucial to support the development, promotion and innovation of these technologies and equipment.

AFTERWORD

"Leaping over the Age of Oil" is an inevitable path forward for China's energy transformation. This pathway represents an evolution of the world's energy use from biomass to coal, then to oil and to renewables, and its significance will become more apparent over time.

One hundred years ago, Henry Ford, the genius behind large-scale automobile production, decided to abandon the development of electric vehicles and turned to the production of fuel vehicles, which triggered the rise of the "Age of Oil." The most important reason for that is that oil was more economically competitive than electricity as a source of energy. A hundred years later, we are at the start of another automotive technology revolution that made electricity become more economically competitive than oil. China's "Leaping over the Age of Oil" initiative faces many challenges. Nevertheless, without challenges, there is no innovation, no change and no progress forward. The flourishing development of the world economy, the rapid development of technology and the catastrophic consequences of climate change have made "Leaping over the Age of Oil" an inevitable choice for China.

The research units participating in the first year of the “China Oil Cap Project” include:

- Energy Research Institute, National Development and Reform Commission
- Chinese Academy for Environmental Planning, Ministry of Ecology and Environment
- China Institute of Water Resources and Hydropower Research
- Institute of Economic Systems and Management, National Development and Reform Commission
- Chinese Academy of Fiscal Sciences
- Zhejiang Center for Climate Change and Low-Carbon Development Cooperation
- SINOPEC Economic and Technological Research Institute
- Innovation Center for Energy and Transportation (iCET)
- Institute for Transportation and Development Policy (ITDP)
- Lawrence Berkeley National Laboratory (LBNL)
- MotionECO

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Appendix I

Overview of the most important parameters for scenario analysis

<table>
<tr><th colspan="2"></th><th>BASELINE SCENARIO</th><th>STRENGTHENED POLICY SCENARIO</th><th>2°C TARGET SCENARIO</th></tr>
<tr><td colspan="2">Definition</td><td>Describes what will happen to oil-related industries under current policies, industry development plans and goals</td><td>Oil consumption in China under stricter enforced oil cap policies in oil-related industries in addition to the impact of current policies and their spillover effects</td><td>Characterizes China's future oil consumption and demand in its pursuit of the 2°C target</td></tr>
<tr><td rowspan="3">Economy and society</td><td>Economy</td><td colspan="3">• The Chinese economy has entered the so-called stage of "new normal": stabilizing around medium to high speed economic growth, slowing down the pace of growth and emphasizing intensified economic reform and restructuring
• The proportion of the tertiary industry will continue to rise, whereas the proportion of the primary and secondary industries will continue to decline, and the proportion of heavy industry will peak and fall back
• Economic growth will become more consumption-driven, and the improvement of consumption levels and changes in consumer preferences will lead to a transformed an upgraded economic structure.
• GDP growth rate will remain 6.5% in 2020, will slow down to 5.5% in 2030, and will further slow down to around 4% in 2050.</td></tr>
<tr><td>Population</td><td colspan="3">• Fertility rates have gradually declined, the population structure shows signs of aging, and the number of working people has declined.
• New birth control policies ： in 2013 the "parents who are only children can have two children" policy was announced, followed by overall implementation of the "two child policy" in 2015.
• The population will reach 1.42 billion in 2020, is expected to peak at a level of 1.45 billion in 2028, and will decline to 1.44 billion in 2040, and 1.40 billion in 2050.</td></tr>
<tr><td>Urbanization</td><td colspan="3">• At the end of 2017, the urbanization rate of permanent residents reached 58.5%, still in the rapid development zone of urbanization (30%-70%), and there is still much room for further development.
• According to the National New Urbanization Plan (2014-2020), the development target of the urbanization rate of permanent residents in 2020 is about 60%, and it is expected to reach 66% in 2030. After 2040, it will enter a period of stable urbanization and development, with an urbanization rate of 75% in 2050.</td></tr>
<tr><td colspan="2">Policy</td><td>• Petrochemical and chemical industry development plan (2016-2020)
• Deepening the reform of the oil and gas system
• Energy conservation and NEV industry planning
• Energy-saving and NEV technology roadmap</td><td>Under the requirements of the basic scenario:
• Promote the popularization of NEVs
• Improve fuel economy standards
• Public transport development planning
• Railway, aviation, pipeline transportation development planning
• Promote the upgrading of the industrial structure of the petrochemical industry</td><td>• Stricter vehicle emission regulations
• Encourage the development of shared travel modes
• Support R&D and industrialization of advanced technologies such as autonomous driving and hydrogen fuel cells
• Control the expanding scale of the petrochemical industry, promote shifting to low-end manufacturing and increase import of high value-adding products</td></tr>
</table>

	BASELINE SCENARIO	STRENGTHENED POLICY SCENARIO	2°C TARGET SCENARIO
Environment	• Achieve the goals for "the Battle for Blue Skies" three-year action plan • Reduce the adverse impact of oil consumption on environmental quality through oil quality upgrades	• Achieve the goals for "the Battle for Blue Skies" three-year action plan • Achieve important goals such as the vision of a "Beautiful China" and other ecological civilization targets	• Achieve the goals for "the Battle for Blue Skies" three-year action plan • Achieve China's goals for the Paris Agreement • Energy consumption paths of related industries need to meet the requirements of achieving the 2°C target.
Transportation	• Transportation demand continues to grow, railway and pipeline transportation volume rises • Passenger car development approaches the European model, with a saturation of 450 cars per 1,000 people. • Fuel economy reaches the corresponding development target in the technical roadmap, 4.5L/100km in 2050 (excluding NEVs) • The average annual driving distance of vehicles is slowly declining. By 2050, passenger cars will reach 13,000 km/year. • 2050 NEV market infiltrate rate reaches 50%; commercial vehicle infiltration rate reaches 30% • Ethanol gasoline is promoted on the national level • Civilian aviation flight time reaches 1.2 times/year/person • Low-sulfur standardization raises the price of marine fuel oil, meeting the marginal conditions of domestic refinery production plants, causing domestic supply to increase significantly from 2020 onwards	• The transportation structure has been significantly optimized: the efficiency of road cargo has increased along with the proportion of railway transportation. • Urban rail transit accelerates development, and the car sharing model becomes more popular. The saturation value of passenger cars will be 350 cars per 1,000 people. • Fuel economy standards are further improved, 4L/100km in 2050 (excluding NEVs) • Under the influence of 10% car sharing, the average annual mileage of passenger cars in 2050 will be 12,000 km/year. • 2050 NEV market infiltrate rate reaches 65%; commercial vehicle infiltration rate reaches 50% • Policies promote the development of biodiesel and bio-jet fuel • Civilian aviation flight time reaches 1 time/year/person • Strictly control large-scale imports and exports. Under general trade circumstances, the domestic low-sulfur fuel oil production costs will be relatively high. After 2020, the supply of domestic low-sulfur fuel oil will be limited.	• The transportation structure as a whole is fully optimized and efficiency is accelerated • Seamless integration of various modes of public transportation, rapid development of automatic driving, and car sharing together are significantly changing the mode of travel, leading to a saturation value of 260 cars per 1,000 people • Fuel economy is improving faster, 3.5L/100km in 2050 (excluding NEVs) • Under the influence of 25% car sharing, the average annual mileage of passenger cars in 2050 is 11,000 km/year. • 2050 NEV market infiltrate rate reaches 80%; commercial vehicle infiltration rate reaches 70% • The cost of biofuels is greatly reduced, the source of raw materials is guaranteed, and it becomes an effective supplement to petroleum. • Civilian aviation flight time reaches 1 time/year/person • Low-sulfur fuel oil is still mainly supplied from abroad, with only a small increase in domestic supply.

	BASELINE SCENARIO	STRENGTHENED POLICY SCENARIO	2°C TARGET SCENARIO
Petrochemical	• Ethylene and polyester consumption will continue to grow • According to the current industrial development model, the petrochemical industry is based on domestic development, the ethylene self-sufficiency rate will reach 85%, and textile exports maintain at a high level • Plastic recycling continues at the current level with a recycling rate of around 10%	• The global industrial layout changes, the chemical industry changes to developing high-end products and some low value-added products will be imported, the ethylene self-sufficiency rate reaches 75%, and textiles are still exported at a moderate level. • Through new policies, the plastic recycling rate will increase to about 15%.	• Domestic consumption will be upgraded, labor cost and the impact of environmental protection will increase, low-end industries will rapidly migrate to other places, ethylene self-sufficiency rate will be equivalent to the current level of 65%, and textile exports will be reduced by one-third. • Plastic recycling technology, cost and application range have been significantly improved, and the recycling rate has been significantly improved to 20%
Others	• Urbanization development continues to drive demand for petroleum products in everyday life and in the construction sector for building materials and such.	• Residents use of natural gas will increase significantly. Road maintenance cycles will be extended, and the oil for non-combustion use is greatly	• New urbanization fully considers environmental factors. It encourages residents to use electricity to satisfy their energy demands. The development of high-energy-consuming industries will be controlled, and road transportation intensity is reduced.

Appendix 2

Main indicators for economic, resource, environment, and energy development during the "Thirteenth Five-Year Plan"

INDICATORS	GOVERNMENT INDICATORS				INDICATORS PROPOSED BY THE CHINA COAL CAP PROJECT	
	2015	2020	AVERAGE GROWTH RATE PER YEAR (ACCUMULATIVE)	PROPERTY*	2020	AVERAGE GROWTH RATE PER YEAR [ACCUMULATIVE]
ECONOMIC GROWTH						
China's GDP（trillion RMB）	67.7	>92.7	>6.5%	Anticipated	>92.7	6.7
Urbanization rate of permanent citizens（%）	56.1	60	[3.9]	Anticipated	61	[4.9]
Added value of service industry（%）	50.5	56	[5.5]	Anticipated	56	[5.5]
RESOURCE & ENVIRONMENT						
Reduced water consumption per 10,000 RMB GDP（%）	-	-	[23]	Mandatory	-	[35]
Reduced energy consumption per unit of GDP（%）	-	-	[15]	Mandatory	-	[18]
The proportion of non-fossil energy in primary energy mix (%)	12	15	[3]	Mandatory	15.7	[3.7]
Reduced carbon emissions per unit of GDP (%)	-	-	[18]	Mandatory	-	[21]

Note：[ ]is a five-year cumulative value;

* The mandatory indicators are to be achieved mainly relying on government planning and regulation, while the prospective indicators are mainly achieved relying on market-oriented mechanism.

INDICATORS		GOVERNMENT INDICATORS				INDICATORS PROPOSED BY THE CHINA COAL CAP PROJECT	
		2015	2020	AVERAGE GROWTH RATE PER YEAR (ACCUMULATIVE)	PROPERTY*	2020	AVERAGE GROWTH RATE PER YEAR [ACCUMULATIVE]
Forestation development	Percentage of forest coverage （%）	21.66	23.04	[1.38]	Mandatory	24	[2.34]
	Forest cumulative area (per 100 million m^3)	151	165	[14]		165	[14]
Air quality	Ratio of days with good air quality at prefecture level and above （%）	76.7	>80	-	Mandatory	>85	-
	Reduce the ratio of $PM_{2.5}$ levels above standard at the prefecture and city level （%）	-	-	[18]		-	[25]
	Ratio of heavily polluted days (or above) at the prefecture and city level (%)	-	-	[25]	Anticipated	-	[30]
Reduced emissions of major pollutants （%）	Chemical oxygen demand (COD)	-	-	[10]	Anticipated		[10]
	Ammonia nitrogen			[10]			[10]
	Sulphur dioxide (SO_2)			[15]			[23]
	Nitrogen oxide (NOx)			[15]			[21]
	Particulate matter (PM)	-	-	-	-		[25]
	Volatile organic compounds (VOC)	-	-	-	-		[18]
	Air ammonia nitrogen	-	-	-	-		[16]

Note：[ ]is a five-year cumulative value;

* The mandatory indicators are to be achieved mainly relying on government planning and regulation, while the prospective indicators are mainly achieved relying on market-oriented mechanism.

CATEGORY	INDICATOR	UNIT	GOVERNMENT INDICATORS				INDICATORS PROPOSED BY THE CHINA COAL CAP PROJECT	
			2015	2020	AVERAGE GROWTH RATE PER YEAR	PROPERTIES	2020	AVERAGE GROWTH RATE PER YEAR
MAIN INDICATORS OF ENERGY DEVELOPMENT								
Total capacity of resources	Primary energy production	100 million tons of coal equivalent	36.2	40	2.00%	Anticipated	36.5	0.16%
	Total capacity of power installations	100 million kW	15.3	20	5.50%	Anticipated	19.2	4.60%
	Total energy consumption	100 million tons of coal equivalent	43	<50	<3%	Anticipated	45.8	1.30%
	Total coal consumption	100 million tons of coal	39.6	41	0.70%	Anticipated	35	-2.40%
	Total electricity consumption	Trillion kW•h	5.69	6.8-7.2	3.6-4.8%	Anticipated	7.32	5.20%
Energy security	Energy self-sufficiency rate	%	84	>80		Anticipated	<80%	
Energy mix	Non-fossil energy installed capacity	%	35	39	[4]	Anticipated	Renewables 37.5 Non fossils >39	[>4]
	Non-fossil fuel generation	%	27	31	[4]	Anticipated	Renewables 26.9 Non fossils >31	[>4]
	Non-fossil fuel consumption rate	%	12	15	[3]	Mandatory	15.7	[3.7]
	Gas consumption rate	%	5.9	10	[4.1]	Anticipated	10	[4.1]
	Coal consumption rate	%	63.7	58	[-5.7]	Mandatory	55	[-8.7]
	Percentage of coal for power generation in total coal consumption	%	49	55	[6]	Anticipated	53	[4]

Note：[ ]is a five-year cumulative value;

* The mandatory indicators are to be achieved mainly relying on government planning and regulation, while the prospective indicators are mainly achieved relying on market-oriented mechanism.

CATEGORY	INDICATOR	UNIT	GOVERNMENT INDICATORS				INDICATORS PROPOSED BY THE CHINA COAL CAP PROJECT	
			2015	2020	AVERAGE GROWTH RATE PER YEAR	PROPERTIES	2020	AVERAGE GROWTH RATE PER YEAR
Energy efficiency	Reduced energy consumption per unit of GDP	%	-	-	[15]	Mandatory		[18]
	Coal consumption used to generate coal-fired power plants	Grams of coal equivalent/ kW•h	318	<310		Mandatory		300
	Grid transportation loss rate	%	6.64	<6.5		Anticipated	<6.4	
Environment protection	Reduced CO_2 emissions per unit of GDP	%	-	-	[18]	Mandatory		[21]

Note：[ ]is a five-year cumulative value;

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