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The Energy Transition in China: Mid-to Long-Term National Strategies and Prospects

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Summary

This report presents an analysis of China's transition to a low-carbon energy system, which requires multi-disciplinary approaches. As a world's energy consumption driver, China will continue to play a significant role in the global energy transition in next few decades and its future choices in the energy sector will have a great impact on global energy demand and supply pattern. On the other hand, China's unique political environment, complex geographic diversity, and ongoing US-China trade conflict have compounded the uncertainties associated with energy transition. To look into the future roles of different energy technologies, the report mainly covers the spectrum of coal, hydro, nuclear, solar and wind, unconventional oil and gas, as well as electric vehicles. With a specific focus on the power sector, the report aims to help understand the prospects for China's energy sector based on current contexts, existing policies, announced national and regional plans, and ongoing debates.

Keywords: China, Energy Transition, Power Generation, Electric Vehicles

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Abstract

This report presents an analysis of China's transition to a low-carbon energy system, which requires multi-disciplinary approaches. As a world's energy consumption driver, China will continue to play a significant role in the global energy transition in next few decades and its future choices in the energy sector will have a great impact on global energy demand and supply pattern. On the other hand, China's unique political environment, complex geographic diversity, and ongoing US-China trade conflict have compounded the uncertainties associated with energy transition. To look into the future roles of different energy technologies, the report mainly covers the spectrum of coal, hydro, nuclear, solar and wind, unconventional oil and gas, as well as electric vehicles. With a specific focus on the power sector, the report aims to help understand the prospects for China's energy sector based on current contexts, existing policies, announced national and regional plans, and ongoing debates.

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1.Introduction

With the US withdrawal from Pairs Agreement, China's growing role in global commitment to carbon emission highlights the significance of its transition to a low-carbon energy system. The country's current policy focus is on improving energy efficiency, vigorously developing renewable energy, and increasing the proportion of low-carbon natural gas and nuclear energy in the energy structure.

As the International Energy Agency (IEA) stated: "Coal is China. China is coal", China is the largest coal producer and consumer in the world, accounting for nearly half of the world's coal consumption. As a pivotal country for the global coal market, China's role in the international context has evolved significantly in recent years. China was still a coal exporter in 2007, while it became the largest coal importer in the world after four years. The coal imports in China reached more than 300 million tonnes (Mt) in 2013, after which time coal demand began to decline and China's domestic coal market became structurally oversupplied.

Hydropower has become the second-largest energy resource after coal in China's energy mix, accounting for around 16 percent of China's electricity generated and 7 percent of its total energy consumed. China possesses the largest hydropower potential in the world due to its vast mountain ranges and numerous rivers.

Nuclear has been a national priority in China's energy strategies as it well serves the short-term and long-term objectives of China's leaders. In the short term, Chinese policymakers aim to achieve modernization of the country and maintain rapid economic growth. The construction of nuclear power plants brings investment in the energy sector and supplements the role that dirty coal has long played in the economically well-developed regions in Eastern China. In the long term, they aim to make China a great power. In the *Mid-to Long-Term Development Plan for Nuclear Power (2005-2020)*, it is mentioned that China will have to strive to develop nuclear fission production before 2050 to reduce pollution and provide enough electricity.

With abundant solar radiation resources, China currently has the largest solar capacity in the world. By the end of 2018, China's installed solar capacity has reached 174 GW and over 70 percent of it comes from large-scale solar power stations. Rich in wind resources, China possesses the potential of over 3.0 TW, with 2.6 TW in its onshore potential, majorly in the "Three Northern" region (Northwest, North, Northeast) in China. China's practical near offshore wind capacity (at a water depth of less than 50m), which will be a development focus by 2030, is estimated to be as much as 500 GW with currently available technologies (IEA & ERI, 2011). Having issued the *Clean Energy Consumption Action Plan 2018-2020*, the Chinese government has placed the need to decrease renewable energy curtailment high on its policy agenda. The plan puts a future emphasis on reforms in China's electricity market, provincial interconnection enhancement, energy storage improvement, and flexibility of the power system.

China possesses the largest technically recoverable shale gas reserves in the world, at approximately 1,115 Trillion cubic feet (Tcf), which is 68 percent larger than those of the US (Reig, Luo, & Proctor, 2014). In 2018, the shale gas production in China was approximately 11 billion cubic meters (bcm), accounting for 6.8 percent of total natural gas production in China. Due to the domestic availability, lower carbon emissions and the benefits of energy independence, the Chinese government has seen shale gas as an enticing alternative to the imported gas and encouraged foreign participation through a public procurement process.

As in many other countries, oil has mostly satisfied the growth in China's transport demand. From 2000 to 2016, 55% of the increase in China's oil demand came from its transport sector (International Energy

Agency, 2017). As a significant reason for China's oil imports, the transport sector has long been important when it comes to China's energy security issue. This fact highlights the need to develop alternative fuel vehicles in China to gradually phase out traditional petroleum fuels.

Table 1 summarizes the electricity development plan by energy resources, which reveals the recent emphases in China's energy strategy. It can help us understand the changes in China's energy mix, especially in the power sector, in which nuclear, natural gas and renewables are gaining more attention.

Index	2015	2020	Annual Growth Rate	Target Type
Share of Non-Fossil Fuels Consumption (%)	12%	15%	3%	Binding
Conventional Hydro Power(GWh)	297	340	2.8%	Expected
Nuclear(GWh)	27	58	16.5%	Expected
Wind(GWh)	131	210	9.9%	Expected
Solar(GWh)	42	110	21.2%	Expected
Coal(GWh)	900	<1100	4.1%	Expected
Natural Gas(GWh)	66	110	10.8%	Expected

Table 1. China's 13th Five-Year Plan for Electricity Development Plan (2015-2020). Created from China's 13th Fiver Year Plan by National Development and Revolution Commission, 2016.

2. Coal

2.1 Context

In the past decades, coal has grown rapidly from 130 Mt (in the year 2000) to 350 Mt (in the year 2013) until the year 2014 when the consumption firstly began to decline. China's coal consumption continued to decrease in the year 2015 and 2016 by 3.5% and 4.7% respectively. However, the data from the National Bureau of Statistics suggests slight increases in the year 2017 and 2018 by 0.4% and 1% respectively (Figure1). National Energy Administration (NEA) provides an explanation for this change as a short-term result from a rebound of energy-intensive industries given China's economic recovery under a better global economic condition. While some analysts in China are concerned about the deeply rooted problems in the country's economic reforms. They question whether the government's economic reform plans are efficient given that China's economy still heavily relies on infrastructure investment and the secondary sector still accounts for a larger contribution than the service sector in Chinese GDP growth. Therefore, it remains questionable whether China can achieve its ambitious targets in the economy, reforms, energy, and climate change at the same time.

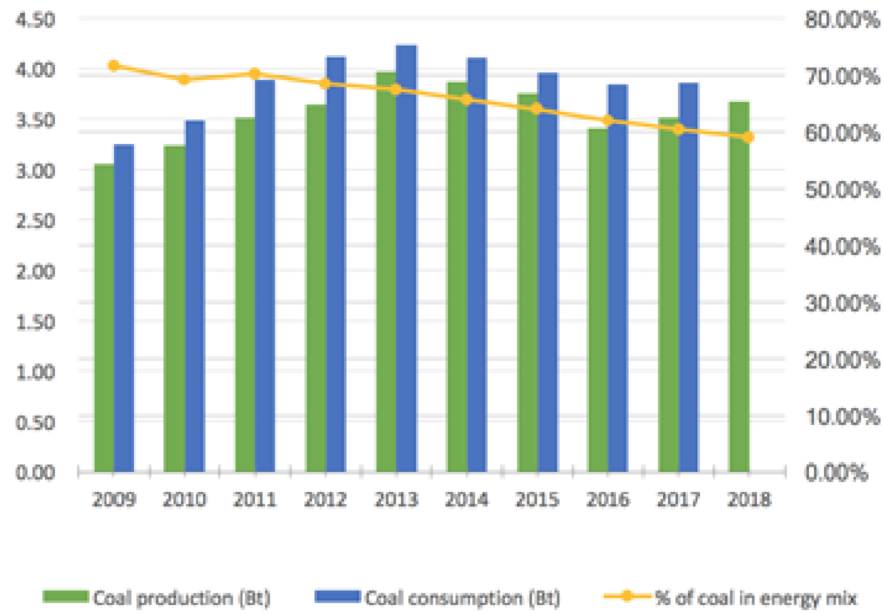

Figure1. Graph of China's Coal Production and Consumption (2009-2018). Reprinted from China Dialogue by H.Feng, Z.Yao and L.Bai, 28 August 2018.

On the other hand, the share of coal in China's energy mix has declined since the year 2011 (Figure1) and China is approaching its commitment to reduce the share of coal as low as 58 percent by the end of 2020. It will be very likely for China to achieve its 50-percent target by 2030 if it keeps the reduction rate in the past eight years. In particular, the growth in the power sector dominated by coal has been significant for China's economic growth over recent decades. Between the year 2000 and 2016, coal power generation capacity experienced a marked expansion, increasing from 235 GW to 945 GW. To solve the problem of overcapacity, China aims to cap coal-fired power capacity at 1,100 Gigawatts (GW) by 2020, through structural reforms in the power sector and the wider use of renewable fuels (National Development and Reform Commission, 2016). However, challenges remain, especially given that China's economic growth is slowing down. The National Power Administration predicts that the rise in electricity consumption will slow to around 3.6 to 4 percent over 2016 to 2020 compared with 12 percent in 2011, resulting in excess coal power capacity (National Development and Reform Commission, 2016). Recent policies aim to reduce coal use through strict controls by stopping new coal-fired power plants and cutting excess coal-fired power capacity. As a critical issue in China, solving the overcapacity in coal will continue to be one of the priorities for the Chinese government in the next decades. Besides, the expanding capacity and contracting demand for coal highlight the significance of structural reforms in the coal industry.

2.2 Plans

In China 13th Electricity Development Five-Year Plan, the total coal-fired power capacity should be capped at 1,100 GW by the end of 2020, around 55 percent of the country's total power output (National

Development and Reform Commission, 2016). At the time of writing, further national targets for the next decade are still under consideration and not yet announced by the National Development and Revolution Commission. On the other hand, China Electricity Council (CEC) recommended China cap coal at 1,300 GW by 2030, a new ceiling that allows the coal power capacity to grow until peaking in 2030 (China Electricity Council, 2019). This target proposed by the largest power producers in China has caused concerns about its effects on global warming. A Greenpeace analysis points out that the CEC's target could make China single-handedly jeopardize the global efforts to keep global warming below 1.5 °C (Myllyvirta, 2019). The 1,300-GW goal is 290GW higher than the current installed coal-fired power capacity, which means that China will still allow a new coal power capacity of approximately 330-490 GW taking account of the retirement of some coal plants (ranging from 50GW to 200GW). With this target in place, China will be able to establish two large coal power plants per month for the next 12 years and allow 300 to 500 coal power stations newly built by 2030 (Myllyvirta, 2019).

2.3 Ongoing debates about prospects for coal in China

The IEA released a report forecasting that global coal demand will be stable through 2023 and China will witness a gradual decline in its coal demand of less than 1 percent annually on average (IEA, 2018). The agency predicts that China's coal demand would fall 0.5 percent per year to 2,673 Mtce by 2023 due to efficiency improvement and expected declines in coal consumption by key sectors, like iron and steel industry (IEA, 2018). Also, certain related policies including China's "Blue Sky" policy will further bring down Chinese coal demand. The IEA believes that China's clean-air measures would help constrain the country's coal demand. In contrast, the China National Coal Association disagrees with IEA and predicts that coal consumption will continue to slightly increase in the next five years and the total coal consumption will remain at around 4 billion tonnes (Institute for Energy Economics & Financial Analysis, 2019). This prediction is based on their prospects for China's macroeconomy to maintain a stable and positive development trend, which would lead to moderate but inevitable growth in total energy consumption.

Regarding the long-term vision, China National Renewable Energy Centre suggests a significant reduction in China's total coal consumption in 2050 under the Stated Policy Scenario and an even more significant reduction under the Below 2°C Scenario, due to the replacement by electricity in the industry sector and renewable energy in the power sector. Under these two scenarios, total coal consumption can be reduced to 737 –387 Mtce in 2050, compared with the level in 2017 at 2806 Mtce (China National Renewable Energy Center, 2019). Another project led by the Natural Resources Defense Council (NRDC) anticipates China's total coal consumption to be reduced to 669.8 Mtce in 2050 under the Below 1.5°C Scenario (NRDC, 2018). This anticipation derives from the Integrated Policy Assessment Model of China (IPAC) by using the result of the EU H2020 project ADVANCE as an assumption that China's CO2 emission to be 230 billion tons in 2050. It also anticipates continued annual reductions in coal-fired power capacity from 2020 to 2050. According to the undertaken analyses, the Below-1.5°C Scenario is very likely to achieve while it requires immediate actions and more aggressive policies and action plans. Key development trends include economic transformation, electrification, and renewable energy penetration (NRDC, 2018).

2.4 CCS and the negative-carbon power generation

On the other hand, China's "new normal" economic growth model has placed more emphasis on environmentally friendly and high-quality growth, which has also led to debates over whether to continue to use coal. In the next 20 to 25 years, it is expected to be a large amount of coal-based electricity and incremental demand for plants. Even though these new plants are as energy-efficient as possible and emit as low as possible, they will still emit large amounts of carbon dioxide. To this end, it is imperative to deploy carbon capture and storage (CCS) technology, which can reduce carbon emissions by up to 90%. Therefore, China's policy focus is expected to be encouraging technologies including carbon-intensive and negative-carbon power generation. Twenty more CCS facilities are under early or advanced development in China, including demonstrations of pre-and-post combustion capture, geologic storage, and CO2-EOR (NRDC, 2018). Over the past few years, China has embraced CCS technology as a significant approach to achieving its carbon reduction targets.

At the time of this writing, China has not yet developed a comprehensive national regulatory framework for its future CCS projects. Meanwhile, a research project led by the National Development and Revolution Commission and managed by Asian Development Bank, suggests a development roadmap for China's CCS (Asian Development Bank, 2015):

1. By 2020, China will have about 5 to 6 full-scaled CCS projects in operation;
2. By 2030, China will be able to establish 100 CCS projects and enter into a new phase of commercial operation;
3. By 2050, the use of CCS technology will be almost universal in China and achieve the need for carbon emission reduction.

The negative-carbon power generation has gained significant progress in terms of its technical and economic feasibility, under the cooperation of Harvard University and institutions from China and Australia. The researchers found that a new process to produce electricity in China by combining coal and biomass energy can reduce CO_2 in the atmosphere if biomass accounts for more than 35 percent of the mix and the waste carbon are captured (Lu et al., 2019). In addition to the technical feasibility, the study also demonstrates the economic viability with Levelized Cost of Energy (LCOE) less than 9.2 cents per kilowatt-hour (around $52 per ton), enabling it to compete with the existing coal power plants in China (Lu et al., 2019). Though related research is still ongoing and putting into action takes more time, this strategy offers an opportunity for China to achieve negative-carbon energy development with large amounts of coal still in use.

2.5 Will China be able to reduce its coal consumption?

It is feasible that China achieves its goals to continuously reduce coal consumption in the next few decades, especially with strong policy control. Three main drivers will help to curtail China's coal consumption: continued economic reforms, development of renewable energy and China's coal-cap policies.

Firstly, coal demand in China, especially in the power sector, is likely to decline as China's economy shifts from the one reliant on energy-intensive industries to the one reliant more on the service sector. The decoupling trend between China's electricity demand growth and its economic growth highlights a shift away from energy-intensive industries (i.e., manufacturing, construction, and power) to more service-based industries (Feng, Tang, & Yao, 2017). In other words, the traditional drivers of coal consumption growth, manufacturing, and construction, in particular, will continue to give way to the less energy-intensive sector in China's economic development. This trend also reflects the efforts of the Chinese government to conduct structural reforms in the energy sector and to improve energy efficiency.

Secondly, the deployment of renewable technologies will also significantly reduce coal-fired power generation. Adjusting the energy structure of energy consumption will have a great impact on coal consumption because the share of coal in the energy mix dropping slightly can substantially reduce the total amount of coal consumption. So far China has already largely invested in hydro, solar and wind. The share of coal-fired power generation in the total generation decreased to 65.2% in 2016 from 67.7% in 2015, due to the new generation from renewable resources (Lin, 2017). This trend is believed to continue. Policies related to renewable energy suggest prospects for renewable energy to gradually replace coal in electricity generation. In 2018, the National Development and Reform Commission (NDRC) mandated six new entity categories that are responsible for meeting the renewables obligations (Patel, 2018). In the same year, China set a target for renewable energy to account for 35% of electricity consumption by 2030 to reduce its reliance on coal. These policies indicate China's strong visions in the long term for the energy system with a larger share of renewable energy.

Thirdly, national and regional coal-cap policies will also help to limit coal consumption and phase down coal's share in the energy mix, especially in the north of China, that has long suffered from air pollution. In 2016, the NDRC and the NEA jointly issued a document to instruct provinces to limit their coal-fired power capacity. Nearly half of Chinese provinces have been told to postpone the construction of new coal power plants and over 100 coal power plants were halted by the State Energy Administration in 2017 (Feng, 2018). However, the current coal policy reversal in China suggests a potential rebound trend in coal consumption in the future. CoalSarm, a global network of researchers working on fossil fuels and alternatives, indicated in 2018 that China was building 46 GW of coal power capacity that had been suspended, based on their analysis of satellite images (Feng, 2018).

2.6 Uncertainties remain

Phasing out coal gradually has been an undoubted topic in China's energy system, while questions are the speed and the challenges ahead. There has been a decoupling trend between electricity demand growth and economic growth in China. In 2014, China's GDP increased by 7.4%, while its electricity demand only grew by 3.8% and the demand for diesel firstly contracted in a decade. This trend implies the possibility of China to sustain economic growth while at the same time reduce electricity consumption. The more critical question is whether the decoupling is temporary or structural (Han, Chen, Long, & Cui, 2018). Debates are ongoing arguing about whether the coal-fired growth is over and whether the coal consumption is still closely related to economic growth in China. Several foreign research institutes including the IEA, IEEFA, and Brookings Institution wrote that China's coal peak may have been reached in 2013 (Yao & Wu, 2017). The IEA further claimed that the diversified energy structure has weakened the positive correlation between Chinese economic development and coal consumption. In contrast, the China Energy Economic Research Center of Xiamen University suggested that coal consumption is still highly correlated with China's economic growth (Yao & Wu, 2017).

Despite the medium-to-long-term policies made in China to control its total coal consumption, uncertainties remain regarding the peak of coal consumption. One critical challenge to bend down the coal consumption curve lies in the possibility of expanding infrastructure construction, which is likely to increase the demand for coal in the future. At present, the four biggest coal consuming sectors in China are power generation, iron and steel industry, the construction material industry and the chemical industry. As an authoritarian regime, China's political legitimacy significantly derives from its economic development and this fact determines that the Chinese central government will always prioritize economic growth despite its bold targets about energy transition and carbon emission. As a foundation for growth and an efficient tool to boost a flagging economy, construction infrastructure has long played a significant role in the Chinese economic system, especially when policymakers are facing great challenges to stimulate the economy. The secondary industry accounted for 40.7% of China's total GDP in 2018 (Statista, 2019). This fact highlights the importance of energy-intensive industries and the difficulty in reducing coal consumption under the pressure of economic recovery in China. Besides, the accelerating urbanization in China makes the task of infrastructure even more arduous. Therefore, the great demand for infrastructure construction, particularly in small and medium-sized cities and villages, is likely to increase the demand for energy-intensive industries such as steel and building materials and further boost the demand for coal.

3. Hydro

3.1 Context

To satisfy the country's large power needs, China has been aggressively building dams. Currently, China has 521 dams registered (NEA, 2019). China's hydropower deployment has entered the rapid development phase in the 21st century, with not only the largest hydropower installed capacity in the world but also increasing cutting-edge technological innovation. By the end of 2018, hydro in China contributed approximately 1200 TWh electricity with an installed capacity of 350 GW (Figure3). In mainland China, there have been more than 640 large hydropower stations with no less than 50 MW each by the end of 2018 (Fu, 2019). Baihetan hydropower projects under construction on the Jinsha River is scheduled for completion in 2022 and will be the world's second-largest power station, with 16 GW capacity (China Daily, 2017).

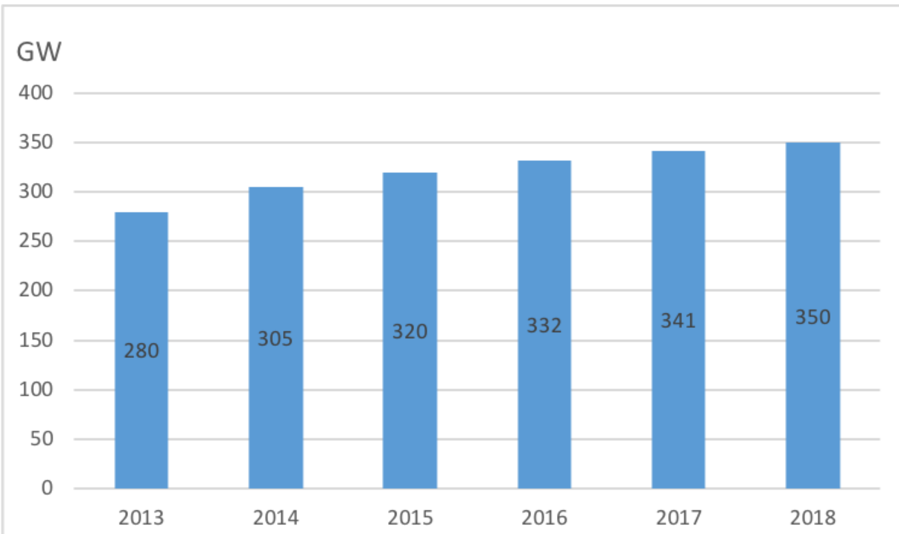

Figure 3. Graph of China Hydropower Cumulative Installed Capacity. Created from data by China Electricity Council, 2019.

3.2 Plans

China's conventional hydropower will follow a "Three-step" development strategy (China Society for Hydropower Engineering, 2015):

1. The first step is by 2020, to achieve a total capacity of 350 GW in conventional hydropower (including small hydropower), with the leading projects in the southwestern region fully initiated and partially in operation.
2. The second step is by 2030, to obtain about 70 GW more capacity than 2020. The planned hydropower base in the southwest region is fully established and the hydropower development of the main rivers such as the Mekong River and the Jinsha River are basically completed.

3. The third step is by 2050, to obtain about 70 GW more capacity than 2030. The planned hydropower base of the large rivers such as the Yalong River, the Dadu River and the Nujiang River (Salween River) is basically developed.

It is worth noting that China's installed capacity has already achieved the target for the year 2020, exceeding 350 GW in 2018. Most of the operated projects are located in the southwest of the country. Until the end of June 2019, specific plans for China's hydropower plants can only be found in *the 13th Five-Year Plan* by 2020. Only targets for general hydroelectric capacity can be found in the official documents while information for detailed power stations in planned is not available. Table 2 summarises the capacity targets and hydropower generation by 2020 and Table 3 summarises the distribution of hydropower plants in China by region by 2020.

Project	Total Installed Capacity (GW) by 2020	Annual Hydro Generation (GWh) by 2020
Conventional Hydro	340	1,250,000
(of which) Large Hydro	260	1,000,000
(of which) Small Hydro	80	250,000
Pumped Storage	40	/
Total	380	1,250,000

Table 2. The 13th Five-Year Plan for Hydropower by Project Type. Created from targets in the 13th Five-Year Plan, 2016.

Region	Capacity(GW) by 2020	Share in National Capacity(%)	Degree of Development (%)
Western China	240	70.6	44.5
Middle of China	63	18.5	90.4
Eastern China	37	10.9	72.1
Total	340	100	51.5

Table 3. The 13th Five-Year Plan for Hydropower by Region. Created from targets in the 13th Five-Year Plan, 2016.

3.3 Cutting back on small hydro

Driven by the need to address the overcapacity issue, the government's 13th Five-Year Plan for the hydroelectric power development proposes to halt the construction of small- and-medium-sized hydropower stations while favoring mega hydro hubs in the west of China despite its massive environmental and social costs. In the short term, China is likely to continue to curb small-scale hydroelectric generation especially as the energy demand in China is slowing down with its economic growth. On the other hand, China is still keen for large-scale dams, which hopefully will help China to achieve its capacity goals in hydroelectricity generation. Backed by the support of the national policy, the installed capacity of large hydroelectricity reached 221.5 GW by the end of the 12th Five-Year (the year 2015), exceeding the planned 192 GW. Large hydro projects not only generate more electricity than small hydro projects but also allow China to leverage over its Southeast Asian neighbors by controlling the flow of dammed rivers.

The future of targeted hydro projects is brighter than nuclear. Long-term safe development in hydro stations aside, dams on average take 8.6 years to build and it usually becomes longer when we take years of planning, contract negotiations and licensing into account (Leslie, 2018). This long period relieves politicians of accountability because the people who initiate the project will no longer be in power.

A few factors can still slow down the construction of large dams in China. Apart from strategic national projects like Three Gorges Dam, which are under direct watch by the central government, uncertainties remain in the construction of other dams. Globally investments in solar and wind energy outpace those in hydropower. Even the Chinese construction giant, the China Three Gorges Dam Corporation, is investing largely in the wind and solar projects. The fact that dams are not cost-effective further compounds investors' concerns. According to the study by Oxford University in 2014 looking into 245 large dams built from 1934 to 2007, dams' actual costs on average are 96 percent higher than estimated and projects' construction takes 44 percent longer than predicted (Leslie, 2018).

In addition, controversies aroused by large dams will make it more complex and difficult for China's top leadership to approve its construction. On the one hand, building dams can satisfy three major needs: to control flood, to generate electricity, and to assist river navigation. In China particularly, flood control has been the most significant objective when it comes to dam building. On the other hand, concerns about large dams still exist. Widespread human displacement, the loss of archaeological and cultural heritage, and the risk of upstream flooding due to silt build-up can affect the final decisions made by Chinese leaders and postpone the actual construction process (Yin, Chang, Gao, Kaminsky, & Reames, 2018).

4. Nuclear

4.1 Context

According to China Nuclear Power Development Report 2019 (Blue Paper) released by China Nuclear Energy Association, by the end of 2018, China has owned 46 nuclear reactors in operation with a capacity of 44.6 GW, and 12 reactors under construction with a capacity of 11GW. The operational capacity has been the highest in history and contributes 4.22% (Figure 2) of total power generation, rising by 15.78% compared with 2017. In the past 20 years, China has witnessed an overall increasing trend in the nuclear share of electricity production (Figure 3). With the ambition to become a nuclear superpower in the world, China has focused on advanced reactor technologies promotion and has become the first country to develop third-generation models such as Westinghouse's AP1000 and the French EPR design.

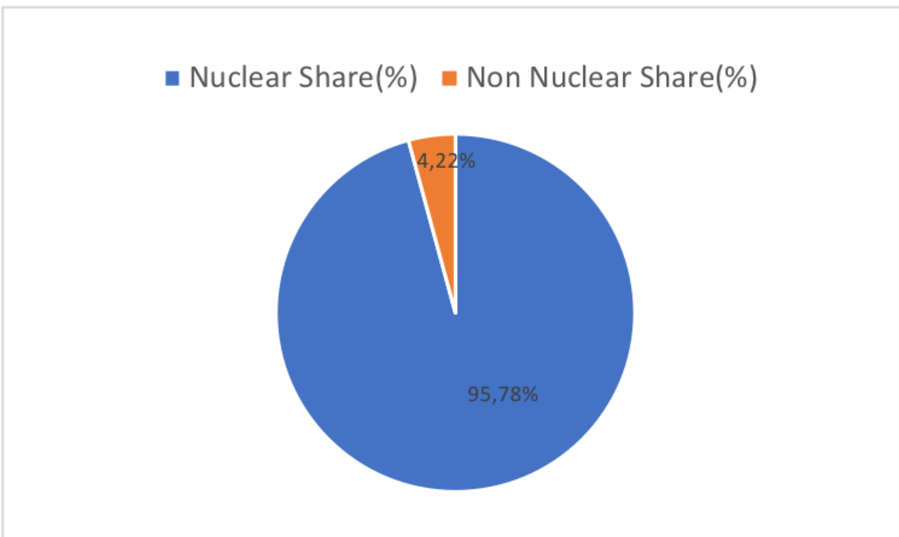

Figure 4. China electricity production share 2018. Adapted from data by IAEA, 2019.

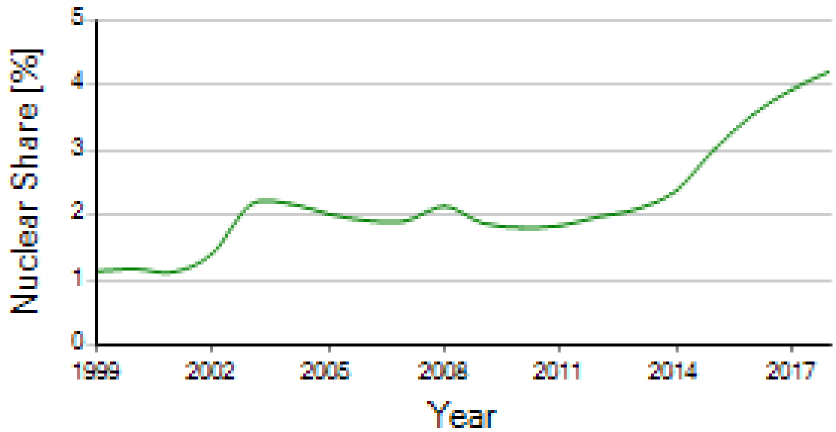

Figure 5. China nuclear share trend. Reprinted from data by IAEA, 2019.

After the Fukushima accident, China froze the plans in *the 12th Five-Year Plan* (2011-2015) to newly establish nuclear power plants. No nuclear project was approved from 2016 to 2018 mainly due to the security concern. This situation continued until the beginning of 2019 when the nuclear reactors in Zhangzhou and TaiPingling were approved and planned to start their construction in June 2019. The change in China's government attitudes about nuclear power primarily comes from the pressure of increasing energy consumption and environmental pollution.

4.2 Plans

Following the aims to increase the share of non-fossil fuels to 20 percent of the energy mix by 2030, so far China's National Development and Reform Commission has announced mid-to long-term plans for China's nuclear power development (China Nuclear Energy Association, 2019):

- By 2020, capacity reaches 58GW with 30GW more under construction, accounting for 6% of total power generation.
- By 2030, capacity reaches 120-150GW, accounting for 8% to 10% of power generation.

A study by Energy Research Institute of National Development and Revolution Commission suggests that China's nuclear power capacity has to reach 554 GW by 2050 so as to realize the target of limiting temperature below 1.5 °C and nuclear power need to account for 28 percent of the country's energy mix (Xiao & Jiang, 2018). At the time of this writing, China has 43 nuclear reactors in plan with a capacity of 50.9 GW, according to the World Nuclear Association. Among these reactor projects, six to eight units are expected to start their construction in 2019 and two units are expected to initiate in 2021 or 2022, while the starting date of the rest of them are not mentioned. Besides, 170 reactor units have been proposed. Among these proposed units, 92 of them are firmly proposed with a capacity of 109.2 GW and 78 of them are further proposals which are less definite or further away (World Nuclear Association, 2019).

China also intends to achieve self-sufficient in nuclear fuel supplies, especially in uranium supplies. With more new nuclear reactors approved and built, China plans to take more control of uranium supplies to meet its fuel needs. UxC reports that China's annual assumption is currently about 9,000 tU and it imported over 115,000 tU from 2009 to 2014, much of which is stockpiled. Despite the stockpiled uranium, China is expected to see a slow increase in domestic uranium production and dependence on imports due to the poor uranium endowment. In the future, China aims to have one-third of its uranium produced domestically, one-third obtained from joint ventures in foreign mines, and the rest purchased on the open market.

4.3 Can China build these nuclear reactors as planned?

The target for 2020 (58GW) is unlikely to achieve as few plants have commenced construction since 2015. After the Fukushima Daiichi nuclear disaster in Japan, domestic opinions in China about the nuclear industry has been more conservative and cautious.

To meet the 2030 development plans for China's nuclear industry, China has to build six to eight nuclear reactors a year under the condition that project approval processes return to normal (Stanway, 2019). If China successfully manages to achieve its targets for nuclear power generation, several hundred power reactors will likely be built by 2050, implementing a closed fuel cycle at an industrial scale (Hibbs, 2018). However, the slow growth in energy demand together with the "New Normal" situation and the knock-on effects of the Fukushima Daiichi accident may undermine the expected nuclear power capacity in China by 2030. It is still too early to predict the future construction of China's nuclear reactors due to formidable unknowns. It is possible that China may be more cautious about nuclear power generation and leave planned and proposed reactors unfinished if China fails to keep the cost advantage of nuclear especially with the reforms in its electricity market. Risk management remains the core of decision-making in the future of nuclear programs (Hibbs, 2018). Despite the urge from the Chinese nuclear industry to accelerate the permit for inland site construction, the Chinese government has revealed an aversion to risk. Chinese government officials are aware that the population will hold the Communist Party accountable in the case of any security issue in nuclear development, which can ultimately threaten domestic stability. Therefore, China's nuclear capacity may decline in the future unless its leaders determine to challenge the country's coal dominance rigorously and balance effectively between renewable resources and nuclear power.

5. Solar and Wind

5.1 Context

Solar

As shown in Figure 6, China has rich solar resources in general with the Qinghai-Tibet Plateau standing out, characterized by total annual irradiation of over 2118 kWh/m^2 in some areas. With abundant solar radiation resources, China currently has the largest solar capacity in the world. By the end of 2018, China's installed solar capacity has reached 174 GW and over 70 percent of it comes from large-scale solar power stations. The country owns several sizeable solar farms, including the world's biggest in the Tengger Desert with over 1,500 MW capacity. Despite with a smaller capacity than solar power stations, distributed solar PV has been growing rapidly (Figure 7). China's installed capacity of distributed solar PV (19.4 GW) in 2017 increased by more than three times than a year before.

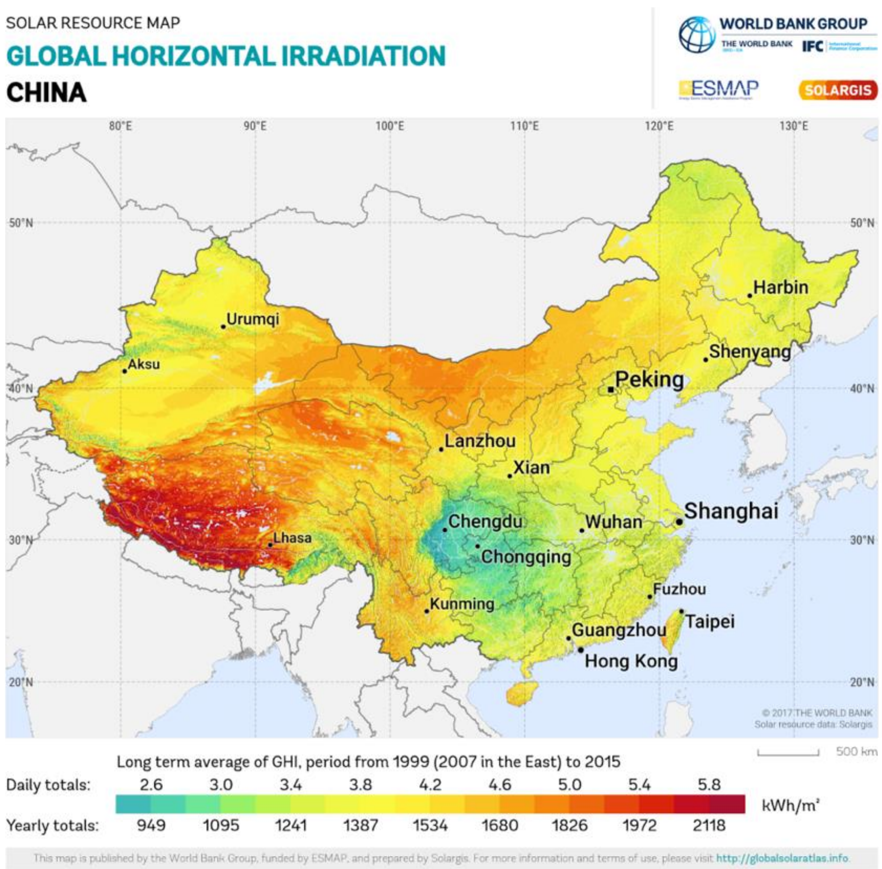

Figure 6. China Horizontal Irradiation. Reprinted from Solar Resource Map by World Bank, 2019.

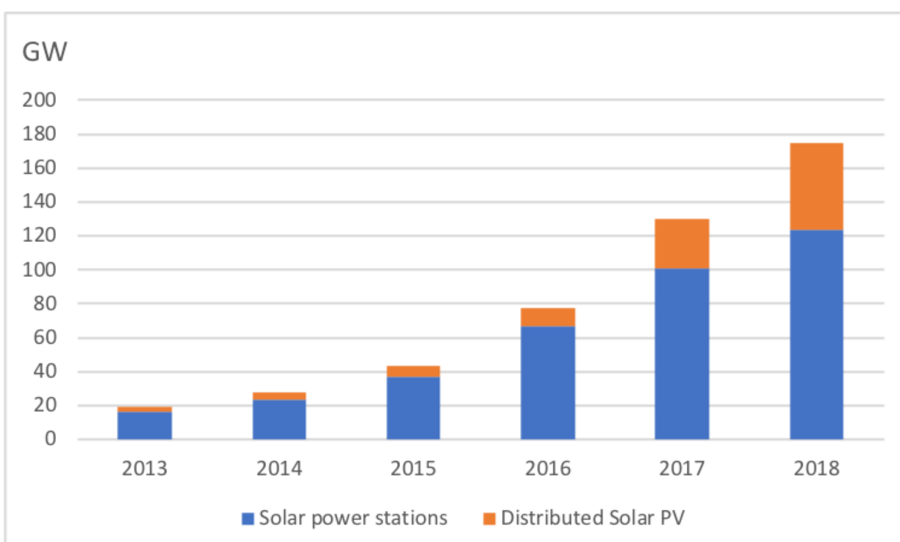

Figure 7. China's Installed Solar Capacity. Created from data by China National Energy Administration, 2019.

In addition to national plans to encourage renewables, the solar boom in China can also attribute to incentive policies and declining costs. Since 2013, China has issued a series of incentive policies including Feed-in Tariff (FIT) for distributed solar PV. The latest national solar subsidy is 0.18 Yuan ($ 0.026) per kilowatt-hour (kWh) and 0.1 Yuan ($0.015) per kWh for commercial use and households, respectively (WRI, 2018). Besides, individual provinces have their subsidies, ranging from 0.05 to 0.55 Yuan/kWh (USD 0,0073-0,080/kWh), lasting from 2 to 20 years. Also, declining costs in PV modules and solar power generated jointly attract more investments in China's solar projects. Globally the average price of PV modules decreased by 79% from 2010 to 2017 and the average cost of solar power generated in China in 2019 is about 0.45 Yuan/kWh (USD 0.065/kWh), a 61% drop from 2010 when China has adopted national FIT for solar power (WRI, 2018).

Wind

Rich in wind resources, China possesses the potential of over 3.0 TW, with 2.6 TW in its onshore potential, majorly in the "Three Northern" region (Northwest, North, Northeast) in China. China's practical near offshore wind capacity (at a water depth of less than 50m), which will be a development focus by 2030, is estimated to be as much as 500 GW with currently available technologies (IEA & ERI, 2011). Due to the distribution pattern, China's wind power is expected to expand wind farms in the north and to be characterized by large-scale, centralized development and long-distance transmission. Meanwhile, the development of wind power in the east will benefit from improved power-grid infrastructure and increasing wind power consumption (IEA & ERI, 2011).

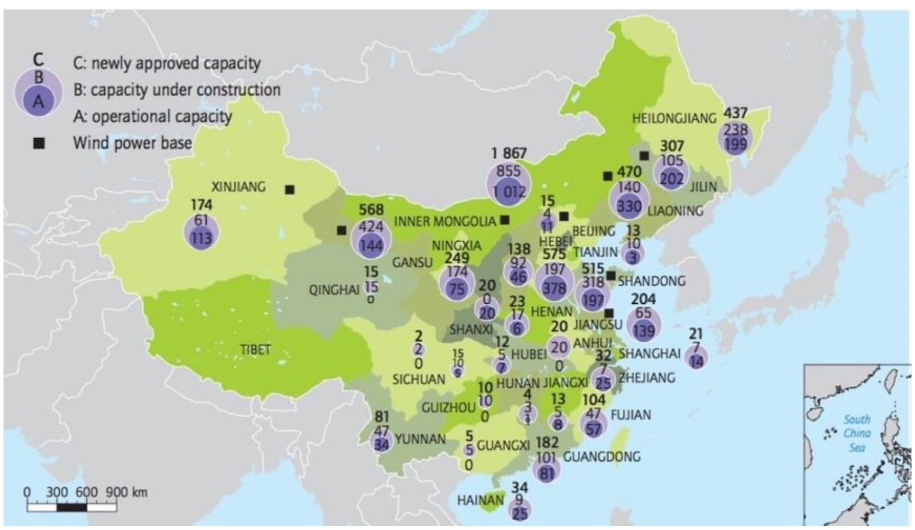

Figure 8. Wind Power Distribution in China. Reprinted from China Wind Energy Development Roadmap 2050 by IEA, 2011.

Faced with international and domestic pressure on carbon emissions, China has elevated the priority of wind energy development in the energy mix. The radically declining turbine prices and Feed-in Tariff for wind power generation have facilitated the rapid expansion of China's wind projects. However, recently the NDRC has decided to cut the tariffs paid to onshore wind projects to 0.29 Yuan ($0.042) per kWh in 2020 with grid price parity applying for all new projects starting from 2021.

China's wind power has been continuously growing and the grid-connected cumulative wind power capacity reached 184.26 GW by 2018 (Figure 9). This capacity is approaching the 210 GW target for wind power by 2020, the target which was mentioned in *the 13th Five-Year Plan*. In particular, China's offshore wind power capacity grew nearly 30-fold in the past six years, from 60 MW in 2013 to 1655 MW in 2018 (Figure 10). At the same time, onshore wind in China has continuously grown in the past few years, with 18 projects approved from 2017 to 2018, exceeding 5367 MW, and 14 of them under construction. As the onshore wind continues to be actively deployed after 2020, offshore wind will also start its early demonstration phase in the next decade (IEA & ERI, 2011).

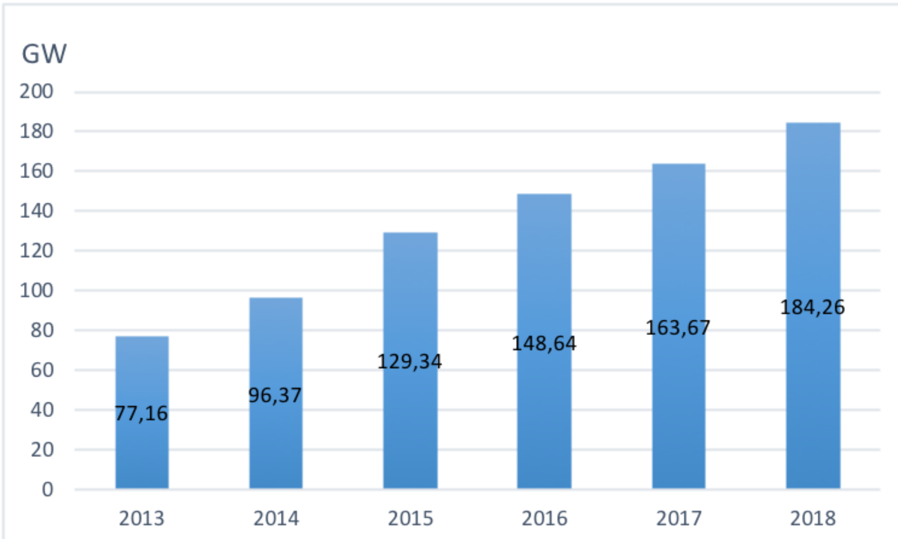

Figure 9. China's Cumulative Grid-Connected Wind Power Capacity. Created from data by China National Energy Administration, 2019.

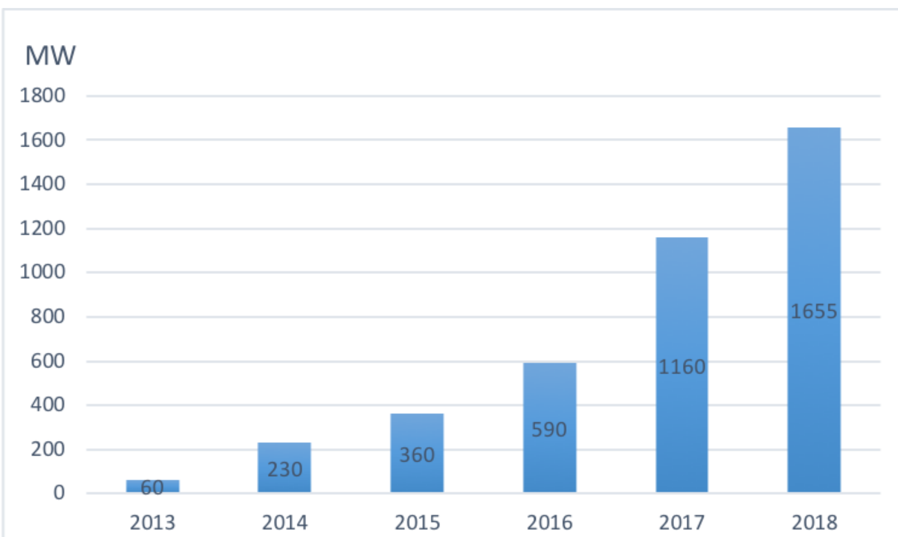

Figure 10. China's Cumulative Offshore Wind Power Capacity. Created from data by Chinese Wind Energy Association, 2019.

5.2 Plans

Renewable Portfolio Standard

China's National Energy Administration issued the renewable portfolio standard (RPS) in 2019, which will become effective in 2020 for five years. Table 4 summarises the standards for different provinces by 2025. This standard specifically sets minimum levels that renewables (Hydropower excluded) should account for a province's electricity consumption, ranging from 5 percent to 13 percent. Big cities like Shanghai and Beijing are assigned for 5 percent level and 10 percent level, respectively. By requiring designated electricity users to purchase an obligated quota of renewable energy certificates from renewables generators, the new RPS is expected to increase China's renewables consumption and to reduce wind and solar curtailment rates. Wind and solar curtailment rates declined to 7 percent and 3 percent, respectively under the government's policy support in 2018 and these rates are expected to fall with increasing consistency across different regions in their dispatching portfolio of renewable energy (AsianPower, 2019). Moreover, the RPS can also be positive for renewable energy companies and increase their investment returns by increasing renewables utilization.

The share of renewables in electricity consumption (2020-2025)	Provinces
5%	Shanghai, Jiangxi, Guangxi, Chongqing, Sichuan, Guizhou,
7%	Jiangsu, Zhejiang, Anhui, Fujian, Henan, Hubei, Hunan, Guangdong,
10%	Beijing, Tianjin, Hebei, Shaanxi,Shandong, Hainan, Yunnan, Shanxi, Qinghai
13%	Neimenggu, Liaoning, Jilin, Heilongjiang, Gansu, Ningxia, Xinjiang

Table 4. The Share of Renewables in Electricity Consumption in RPS. Created from information released from National Energy Administration, 2018.

Goals for Solar

To the date of this writing, the officially mentioned target for solar electricity generation can only be found in *Solar Power Development in the 13th Five-Year Plan* that by 2020 China's solar electricity generation capacity reaches 110 GW with 105GW by solar PV. It is worth noting that China has already surpassed its target for 2020 three years ahead of schedule and its installed capacity of solar PV has even reached 165 GW by the end of September 2018. Further targets for solar by 2020 has been under negotiation this year and many regional governments in China have proposed it to be more than 250 GW (NEA, 2018).

Although official targets for 2025 are not yet released by China's National Development and Reform Commission (NDRC), it has published *China 2050 High Renewable Energy Penetration Scenario and*

Roadmap, within which the targets for China's solar power under a basic scenario to offer 150, 510, and 2100TWh by 2020, 2030, and 2050 respectively (Energy Research Institute of NDRC, 2015).

Goals for Wind

Although the Chinese government has not announced its long-term targets for wind power, Energy Research Institute (ERI), a national think tank under NDRC, released *China Wind Energy Development Roadmap 2050*. Released by an institute offering support to the Chinese government regarding energy strategies and plans, this roadmap to some extent can help us get a general idea about plans for China's wind power by 2050. The report shows that China will be able to obtain 1,000 GW capacity of wind power, accounting for 17 percent of its total electricity demand, and reduce carbon dioxide emissions by 1.5 Gt (Giga tonnes) every year by 2050. On reaching this goal, China could reach 200 GW and 400 GW of wind power by 2020 and by 2030, respectively. The roadmap also demonstrates the future distribution of wind power. Before 2020, onshore wind power will remain dominant and near offshore wind power will develop at the demonstration stage. From 2021 to 2030, onshore wind and near offshore wind will develop simultaneously, with far offshore wind in the demonstration. After 2030, onshore and offshore wind will be fully deployed in the western, central, and eastern China.

Table 5 summarises the targets for China's wind power development during three periods: present to 2020, 2020 to 2030, and 2030 to 2050.

Year	By 2020	By 2030	By 2050
Annual Newly Installed Wind Capacity (GW)	15	20	30
Cumulative Wind Capacity (GW)	200	400	1000
Share of Wind Power Generation in Total Electricity Generation	5%	8.4%	17%

Table 5. Targets for Wind Power by 2050, Source: China Wind Energy Development Roadmap 2050

According to *China's Energy Technology Innovation Five-Year Plan,* wind energy will continue to be a focus in the long term and China aims to achieve over 210 GW of grid-connected wind energy capacity, with 5 GW of it to be offshore wind. By 2020, electricity generated by wind power should reach 420 TWh, accounting for around 6 percent of total electricity generation in China. In comparison, the US has set targets for wind power to account for 20 percent of its total electricity generation by 2030 (Prosser, 2019). Responding to the policy by the central government, some regional governments in China have announced their plans for offshore wind deployment. For instance, Guangdong province has released its Offshore Wind Development Plans (2017-2030), mentioning that by 2020 the province ought to have 12 GW capacity of offshore wind under construction and by 2030 have 30 GW capacity of offshore wind in operation.

Goals for Offshore Wind

The 13th Five-Year Plan sets a national target for grid-connected offshore wind power capacity to surpass 5 GW and capacity under construction to reach 10 GW by 2020. However, other specific targets for China's offshore wind power in the long term are not available since the Chinese government released a document in 2016 to simplify the administration in offshore wind management. Named *Measures for Management of the Development and Construction of Offshore Wind Power*, the document aims to improve the flexibility of China's offshore wind power development and accelerate regional developments of offshore wind. To this end, the National Energy Administration will no longer adopt a unified national plan for offshore wind power development and construction plan, instead, projects will be approved by each regional government.

5.3 How much electricity will be generated by renewables in China by 2050?

About the future growth in wind capacity, there are different opinions. Some international organization such as IRENA envisage in its REmap 2030 that China would see a five-fold increase in its onshore wind capacity from 91 GW in 2013 to 500 GW by 2030 and 60 GW more in offshore wind capacity (International Renewable Energy Agency, 2014). WWF (World Wildlife Fund) released a report in 2014 predicting that renewables will account for 80 percent of China's electricity supplies by 2050 (WWF, 2014). While some scholars in China hold the view that this 80 percent target can hardly be achieved especially when the curtailment issue is not solved and new renewable power capacity is hard to be approved to get grid-connected. Lin Boqiang, the Chief of China Institute for Studies in Energy Policy, openly challenged the WWF report by saying that the 80 percent target is impossible for China given that hydro resources have almost been fully deployed and wind and solar, which now only account for about 4 percent of China's electricity generation, can hardly see further expansion. Thus, there is little space for China to boost the share of renewables in its energy mix by 2050. The rapid growth in renewables in recent years largely benefits from some special conditions, which will not permanently facilitate the expansion of renewables. For instance, the US and EU's anti-dumping measures for Chinese solar power products allowed the domestic solar manufacturing industry to grow rapidly. Meanwhile, the small base of China's renewable energy highlights the incredible growth in this field, but it is unlikely to last long in the future.

A study, done by the China National Renewable Energy Center and a variety of other Chinese organizations with support from the U.S Department of Energy, suggests technological and economic feasibility for China to have renewables accounting for over 60 percent of its total electricity consumption by 2050 (Magill, 2015). The study further shows that China is expected to go beyond that and achieve more than 85 percent of its electricity from renewable energy and 64 percent of its electricity from wind and solar power.

Although critics in China question whether these goals can be achieved due to the relatively higher cost of renewables than fossil fuels, some Chinese scholars like Wang Zhongying, a government official and the director of the China National Renewable Energy Center, are positive and believe that the successful high penetration of renewables in Germany and other countries in Europe have proved that China can do it as well (Magill, 2015).

In particular, bottlenecks in the grid connection and green power curtailment are critical issues for future solar and wind power deployment. For instance, the "Three North" area in China is and will still be the concentrated region for large wind farms. However, the existing power grid infrastructure in the north is not sufficient to match large-scale wind power generation, which contributes to the difference between technical potential and actual power generation. Besides, the fact that China's wind power generation is not living up to its potential compounds uncertainties in a continued and rapid expansion of China's wind sector.

To achieve national goals, a recent study (Huenteler, Tang, Chan, & Anadon, 2018) underscores that China will have to use policy tools to deal with the gap between actual performance and technical potential, which is significantly driven by grid-connection delays, curtailment, suboptimal sitting and technology choices (turbine model selection and hub heights). China is expected to install wind turbines of a capacity of 2400 GW by 2050 and generate 5350 TWh wind power (or 35% of total generation) every year (Energy Research Institute of NDRC, 2015). However, the study points out that China's wind sector would generate 1605 TWh electricity per year less than predicted if China continues to produce from its current installed fleet of turbines at historical average capacity factors.

6. Shale gas

6.1 Context

China possesses the largest technically recoverable shale gas reserves in the world, at approximately 1,115 Trillion cubic feet (Tcf), which is 68 percent larger than those of the US (Reig, Luo, & Proctor, 2014). In 2018, the shale gas production in China was approximately 11 billion cubic meters (bcm), accounting for 6.8 percent of total natural gas production in China. Due to the domestic availability, lower carbon emissions and the benefits of energy independence, the Chinese government has seen shale gas as an enticing alternative to the imported gas and encouraged foreign participation through a public procurement process. Oil and gas giants including ExxonMobil, Royal Dutch Shell, and Total have signed deals with China to explore its shale resources.

Figure 11. China Shale Gas Distribution. Reprinted from 'China's shale revolution: will it take off?' by L. Hornby and E. Crooks, 2014, China Dialogue.

6.2 Plans

The Chinese government has reduced its goals for shale gas extraction:

i. By 2020, the annual production of gas from shale should reach 30 bcm (1.06 Tcf), which was reduced in 2019 from the target of 60 -100 bcm (2.11-3.53 Tcf) per year released by China Energy Administration in 2011;
ii. By 2030, the annual output of shale gas in China should further reach 80 to 100 bcm (2.83-3.53 Tcf).

To achieve this ambitious target, CNPC and China Sinopec will play a significant and leading role. In response to President Xi's instruction to boost national energy security, state oil majors in China have been expanding their shale gas capacity. Sinopec contributed 6.02 bcm (0.21 Tcf) shale gas in 2018 and it has announced to produce 7 bcm (0.25 Tcf) shale gas annually by 2020. CNPC produced 4.27 bcm shale gas in the Sichuan basin in 2018, a year-over-year growth of 40 percent (Xin, 2019). Also, the company has announced its ambitious goals in the shale gas sector for the next decade:

i. By 2020, the company will be producing 12 bcm shale gas annually;
ii. By 2025, the company will be producing 22 bcm shale gas annually, with 1,300 new drilling wells built up from 2020 to 2025;
iii. By 2030, the company will be producing 42 bcm shale gas annually, with 2,300 new drilling wells built up from 2025 to 2030.

However, China is unlikely to achieve its 2020 target. Currently, three main projects operating in the Sichuan Basin will add nearly 700 more new wells between 2018 and 2020, with investments totaling 37 billion RMB (5.5 billion USD). Wood Mackenzie estimates that China will be able to produce 17 bcm (0.60 Tcf) shale gas by 2020, missing its national target by a large margin (Wood Mackenzie, 2018). The energy consultancy company suggests that China will have to add 725 additional wells in addition to those 700 new wells by 2020 so as to meet the 30-bcm target. The number will increase if productivity degradation is also taken into account. Therefore, it will be a massive task for Chinese national oil companies to double the number of investments.

6.3 A shale gas boom in China is not yet anytime soon

Despite the increasing number of wells, the progress in China's shale gas exploration has been very slow and the future seems cloudy. China's shale gas production in the next decade will not see substantial growth and overcoming technical barriers to large-scale extraction will take some time. In addition to the extraction techniques required by the deeply buried China's shale reserves, some Chinese scholars believe that limited supplies of water in China's promising areas for shale gas, the Tarim Basin in the northwest, for instance, is a more serious problem. Over 60 percent of shale resources in China are located in areas of high and extremely high water stress or arid conditions (Figure 12). Not to mention the competition with agricultural and industrial water users in the areas of high population density. Other obstacles include the lack of pipelines in China allowing gas to be transported and the competitive industry, which facilitated the shale revolution in the US.

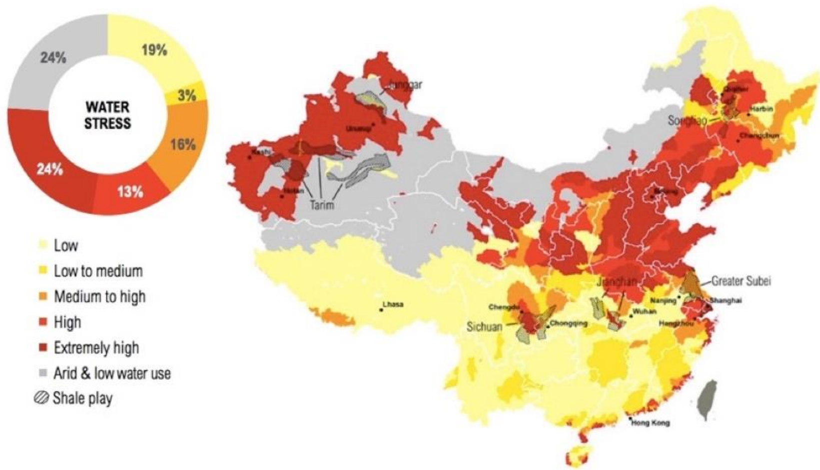

Figure12. Shale Plays and Baseline Water Stress in China. Reprinted from 'Global Shale Gas Development' by WRI, 2016.

Though China is hoping to replicate the success in the US, the shale gas in these two countries is different not only in geological sense but also in market structures. It took the US more than 30 years to realize the shale revolution and become the world's top oil producer. The country's success is believed to result from a combination of several key factors: responsive capital markets, an open and competitive oil and gas industry, well-developed network infrastructure, as well as strong property rights (Wood Mackenzie, 2018). On the one hand, China's shale gas reserves are unique because most of them are more tectonically fractured and less pressured than those in the US, which means that the extraction process in China need deeper wells and thus leads to more technical challenges and higher costs. On the other hand, unlike the US where small- and medium-sized companies actively participate in the competition to unlock oil and gas, two state-owned energy groups are dominating shale developments in China: China Sinopec and China National Petroleum Corporation (CNPC). This structure of China's oil and gas industry rules out the possibility to improve extraction techniques and reduce costs through dynamic market competition.

Moreover, the tensions between the US and China could bring obstacles to energy cooperation. IEA estimates that the US will produce about 40 percent of global new natural gas in the next four years, becoming one of the three biggest LNG exporters. At the same time, natural gas demand in China will increase by 8.7 percent every year to 2022, largely due to Beijing's commitment to solving the air pollution issue (Minxin, 2019). This trend would require China to double its natural gas imports in the next three years and the US will remain one major natural gas supplier for China in the next decade.

China's abundant shale gas resources bring more optimistic views about satisfying China's fossil fuel demands in the future. However, China's shale gas exploration is still in its infancy and technologically and operationally relies on support from the US, which has hosted an oil and gas industry forum on an annual basis with China for nearly two decades to bring together business and government leaders working in the sector. Thus, ongoing tensions between the US and China have added uncertainties in China's potential fossil fuel resources deployment. Although it is still too early to predict the final result of the trade war between these two superpowers, the odds currently tend to favor the US, which is a stronger power and showing its willingness to defeat China at all cost. Despite the endowment of its shale gas resources, unknowns remain in how much of them can be used without experiences and advanced technologies imported from the US.

Moreover, potential safety risks and environmental concerns about shale gas mining has caused controversy in China. Early this year, earthquakes linked to fracking in Sichuan province, which killed two people and injured twelve, caused protests against shale gas extraction and forced the local government to halt operations temporarily. However, the public response is unlikely to reduce the Chinese government's ambitions to achieve its gasification initiative.

7. EV

7.1 Context

As the largest electric vehicle market in the world, the annual sales of EV in China keep growing. Despite the slight decline of its total vehicle sales, NEVs sales in China reached 1.256 million in 2018, accounting for 4.4% of its total new car sales (Figure13). Policies and subsidies highlight the Chinese government's pushes for so-called new energy vehicles (NEVs include BEVs, PHEVs, and FCEVs) to replace internal combustion vehicles (ICEs), due to concerns about China's energy security, manufacturing development, as well as carbon emissions.

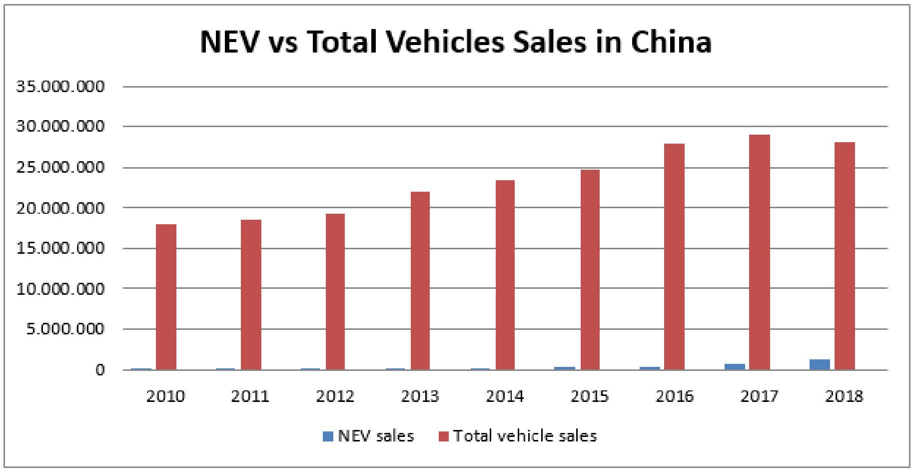

Figure13. New Energy Vehicle Sales and Total Vehicle Sales in China. Created from data by China's National Information Center, 2019.

By the end of 2018, the number of new energy vehicles in China has reached 2.9 million, accounting for 53% of global new energy vehicle ownership. This trend marks China's significant role in reducing carbon emissions and tackling climate change. In its climate pledges, China announced three major objectives (International Energy Agency, 2017):

i. To achieve peak CO2 emissions around 2030 and make best efforts to peak earlier.
ii. To lower CO2 emissions per unit of GDP by 60-65% by 2030, against a baseline of 2005.
iii. To increase the share of non-fossil fuels in primary consumption to around 20% by 2030.

To keep its promise in the Paris Agreement, China has adopted several policies for EVs and announced future development plans based on current transportation patterns:

1) The growing fleets of motor vehicles with a large share of national private cars: China has one of the fastest-growing fleets of motor vehicles in the world (Walsh, 2004). According to China's Ministry of Public Security, the national car ownership has reached 250 million by the end of June in 2019. Particularly, private cars' ownership has reached 198 million, accounting for 79.2% of the total ownership. The automobile fleets in China have grown rapidly and thus brought several problems including an increase in traffic accidents, traffic congestion as well as air pollution.

2) Traffic congestion: China's car density on the road is about 200 cars/km on average, as many as Los Angeles, one of the most congested cities in the US. The number is even higher in some tier-one cities like Beijing and Shanghai. To solve this problem, the government has tried to restrict the number of petrol cars with an internal combustion engine on the road through license plates restriction. In contrast, it is easier to get a license plate for an EV. In this way, the Chinese government hopes to encourage the development of EVs while at the same time control the congestion problem ("Car Density on China's Roads Rivals That of Los Angeles," 2013).

3) Air pollution: Vehicle emission has been identified as a major source of air pollution in many Chinese cities. EVs are expected to play a significant role in reducing China's carbon emissions and improve its air quality. However, largely relying on coal to generate electricity will undermine the effectivity of China's EV strategy.

4) Vehicle ownership imbalances: Although car ownership in both urban and rural areas have seen rapid growth, substantial imbalances in these areas still exist. In 2017, every 100 households in Chinese cities owned 37.5 cars on average, increasing from 15.2 in 2013 (increase by 146%). In contrast, every 100 households in Chinese rural areas own 19.3 cars on average, seeing a marked rise from 9.4 in 2013 (increase by 94.9%). With EV sales encouraged in China, these imbalances are expected to increase given that most EVs are sold in cities rather than rural areas in China (Peilin, Guangjin, & Yi, 2018).

7.2 Plans

I. **Production and sales of EV continue to grow**: On the one hand, China has released several national documents identifying its plans to encourage EV sales. So far, the national policy documents mentioning the mid- to long-term plans for NEV in China primarily are *Energy-Saving and New Energy Vehicles Industry Development Plan*, *Made in China 2025*, *Automobile Industry Mid-and Long-term Development Plan*, as well as *Energy-Saving and New Energy Vehicles Technical Route.*

   Table 6 summarises specific targets mentioned in these documents, including that China's NEV cumulative production and sales reach 5 million by 2020 and NEV annual production and sales reach 2 million NEV in 2020 and 7 million in 2025. On the other hand, Chinese individual automobile companies have announced their mid-term market plans. Companies such as SAIC Group and BAIC Group have set their sales targets at 600,000 and 800,000 by 2020. Besides, the BAIC Group and Haima Automobile Group promise to stop selling ICEs by 2025. In this sense, national goals are more likely to be achieved based on these market players' joined efforts.

   The Chinese government has set several objectives and specific targets for BEV, PHEV, and FCEV respectively. Table 7 summarises deployment targets for different types of NEV currently in place for the 2020-30 timeframe (Timeline document 2019).

Policy Document	Index	2020	2025	2030
The Development Plan for the Energy-Saving and New Energy Vehicle Industry	Cumulative NEV Sales and Production	5 million	/	/
Made in China 2025	Self-owned Brand NEV Annual Sales	1 million	3 million	/
	Share of Self-owned brand NEV	70%	80%	/
The Medium-and Long-Term Plan for the Vehicle Industry	NEV Sales	2%	7%	/
	Share of NEV Sales	6.7%	>20%	/
	NEV in use	/	200 million	/
Energy-Saving and New Energy Vehicles Technological Route	Share of NEV Sales	7%	15%	40%

Table 6. Mid- to Long-Term Plans for NEV in China. Created from targets mentioned in several policy documents.

Year	2020	2025	2030
Annual Sales of BEV and PHEV	2 million	5-7 million	>15 million
Annual Sales of FCEV	5,000	50,000	1 million
Market share of NEV	6%-7%	15%-20%	>40%

Table 7. Mid- to Long-Term Plans for different types of NEV in China. Created from targets mentioned in several policy documents.

II. **Fast growth in charging stations, ahead of EV**: The growing demand for charging stations, encouraging policies will be two main drivers. As China's EV market is expected to expand, the demand for electricity and charging stations is thus expected to grow. Until the end of 2018, the total number of charging infrastructure in China has reached 760,000, with 300,000 public charging stations and 460,000 private ones. Compared with 2017, the total number of charging stations in China has increased by 72%, especially private charging stations have nearly doubled. *(Timeline to Phase Out Traditional Fuel Vehicles in China 2019)*

The Chinese government has promoted the development of EV charging infrastructure as a matter of national policy. The development of charging stations also has a national policy to back up: "moderate forward construction" has been written into *the EV Charging Infrastructure Development Guidelines (2015-2020)*. This policy identifies the priority of EV development in the next step and its significance is highlighted by the "chicken and egg" dilemma in recent years about whether to build charging stations first or to develop EV first. The guidelines ambitiously call for more than 120,000 EV charging stations and 4.8 million distributed charging posts to satisfy more than 5 million EVs by 2020 to almost guarantee that one EV has one charging station. However, this goal is unlikely to achieve unless China will build more than 4 million charging posts in two years. Also, the ratio of EV and charging posts is hard to be 1:1 shortly even with the guideline to moderately develop charging stations forward. The director of the information center of the Chinese EV Charging Infrastructure Promotion Alliance, Tong Hongqi, challenged the standard for the ratio of EV and charging stations to be 1:1. Instead, he argues that 2:1 or 2.5:1 would be ideal in China to avoid wasting public resources (Hongqi, 2019).

China intends to develop the charging infrastructure differently in three identified areas based on local circumstances (Figure 14): the rapid development area in the Eastern China(Red area: 7,400 charging stations and 2.5 million charging posts), the demonstration and promotion area in the middle of China (Blue area: 4,300 charging stations and 2.2 million charging posts), and the active promotion area in the western China (Yellow area: 400 charging stations and 100,000 charging posts).

Figure 14. China's Regional Construction Goals for EV Charging Infrastructure. Reprinted from *EV Charging infrastructure Development Guide*, p.12.

III. **FCEV is one significant focus in the future**: As written in the *Energy Technology Revolution Innovation Plan (2016-2030)*, FCEV will be a focus in China's EV development in the future. The plan identifies the goal that by 2030 China is expected to have core technologies of fuel cells and to achieve the large-scale demonstration of fuel cells as well as hydrogen fuel. Technically, the life cycle of the PEMFC, SOFC, and MeAFC distributed generation system exceed 10,000hr, 40,000hr, and 10,000hr, respectively. By 2050, China is expected to realize the universal application of hydrogen fuel and fuel cells, and breakthroughs toward the production and the use of hydrogen. Another official document named *Energy-Saving and New Energy Vehicles Technology Roadmap* sets the target for the annual sales of FCV to achieve 1 million by 2030. By 2025, hydrogen will be generated by renewable resources and industrial by-products such as coke-oven gas, while by 2030 it will entirely come from renewable resources.

The supply of hydrogen will be a critical issue for China to address in the future. Producing hydrogen from renewables is still in its infancy in China due to the technological barriers and high costs. Therefore, China's pathway for its hydrogen production is to first utilize cheaper fossil fuel resources and eventually transition to the full use of renewables. China has newly established 6 large-scale coal hydrogen projects from 2010 to 2018, producing hydrogen 80.5 million m3/hour (Asian Chemical Consulting, 2018). The production methods are planned to shift towards more sustainable ways after keeping traditional hydrogen production methods.

The specific targets for FCEV are summarized in the table below.

Year	**2020**	**2025**	**2030**
FCEV Sales	5,000	50,000	1 million
Hydrogen Refilling Station (HRS)	100	300	1,000
Hydrogen Supply	Fossil and renewable resources		Renewable resources

Table 8. Mid- to Long-Term Plans for China's FCEV. Created from targets mentioned in several policy documents.

Compared with the ambitious national prospect for FCEV, Chinese local governments seem more conservative. For instance, as a leader in the Chinese FCEV industry, Shanghai has outlined three development phases in the published *Fuel Cell Vehicle Development Plan*: short term (2017- 2020), medium term (2021-2025) and long term (2026-2030). In the short term, Shanghai plans to build 5-10 HRS and deploy 3,000 FCEV in the demonstration by 2020. In the medium term, Shanghai should own 50 HRS and 30,000 FCEV deployed by 2025. In the long term, Shanghai expects the value chain output to be 300 billion RMB (43.6 billion USD) by 2030, without mentioning an exact number for FCEV.

IV. **Marketization will be accelerated and take place of the current policy-oriented EV market in China:** China's new energy vehicles are entering a new generation featured by high-quality development with the integration of electrification and intelligent networking. At the same time, China aims to accelerate the marketization of EV and one of its current approaches to sustain the growth momentum with subsidies fading out is the dual-credit theme, which sets a minimum binding requirement for car producers about the NEVs production. To meet these requirements, car manufacturers in China need to produce or import NEVs or purchase NEV credits from other manufacturers who have excess credits.

In addition to producing NEVs, car producers can also amass credits by producing gasoline They can amass credits by producing gasoline vehicles with fewer emissions than the country's standards or by producing electric cars, plug-in hybrids, and fuel cell vehicles. The credit trading mechanism can offer some flexibility for this mandate. However, it is still expected to put much pressure on car producers, especially traditional ones. In 2018, among 141 passenger car producers in China, 75 of them failed to meet the minimum credit requirements set by the dual-credit scheme and had to purchase credits from other companies (Fusheng, 2019). Thus, this mandate is considered a significant step toward China's EV marketization by encouraging competition among companies and investments in their EV business.

V. **Focus on EV technology innovation**: In line with goals mentioned in *the 13th Five-Year Plan for Energy Technology Innovation (2016-2020), the Energy Technology Revolution Innovation Plan (2016-2030)* sets targets for China's innovation in energy technologies beyond that timeline until 2030. China's EV development has entered a new phase after the early stage when most EVs were adapted from existing gasoline vehicles and policies focused more on growth and less on quality. The policies implemented recently show that China aims to improve the quality of its EV in the future with policy and finance encouragement for its technological improvement.

VI. **Aim to build a mature EV market with China's self-owned brands**: According to the *Automobile Industry Mid-and Long-term Development Plan (Plan)* published by the Ministry of Industry and Information Technology of China joined by the National Development and Reform Commission in 2017, China aims to become a top automobile powerhouse around the world in 10 years. Particularly, the Plan visions China to own NEV companies ranking among the top ten in the world by 2020 and be able to develop world-class intelligent connected vehicles by 2025. The share of R&D expense should account for 4% of the "backbone" companies' total revenues by 2020 and 6% by 2025. The Plan also identifies specific binding targets for vehicles' fuel usage. By 2025, the average fuel consumption of new passenger cars should decline to 4.0L/100km and NEVs should meet international standards for carbon emissions and fuel consumption.

7.3 How to maintain sustainable growth even without financial subsidies?

With the subsidies phased out, whether EVs sales in China can still maintain its fast growth remains uncertain. Now China is shifting EVs market from completely policy-oriented into both market and policy oriented. China has announced that it will gradually shift from direct subsidies to non-monetary incentives after 2020. According to the newest subsidy policy, all regional subsidies are canceled and the highest national subsidies for BEVs and FCEVs are reduced by half to 25,000 RMB (3,637 USD) and 10,000 RMB (1,455 USD), respectively. EVs are attractive in China now, especially in some Tier1 cities, largely due to a series of subsidies and its exemption from license-plate lotteries that apply for ICEs. How to minimize the negative effects on NEV sales after subsidies exit will remain a great challenge for policymakers.

On the one hand, phasing out subsidies may impose pressure on the Chinese EV market with a probable decrease in its EV sales. Since Beijing adopted tougher subsidy policies for EVs and raised the standards for subsidized vehicles this year, it has seen a sharp slowdown in NEVs sales due to the price rise. The growth of sales in May only rose by 1.8% from last year, in contrast to 18.1% in April and 62% in 2018. On the other hand, the cancellation of subsidies can also help accelerate the marketization of Chinese EVs by allowing more advantages for those companies with competitiveness. The government data shows that about 330 EV companies in China have been registered for subsidies (Wu, Sun, & Zhu, 2019). Among these companies, some of them are so reliant on government support that they may lose their market competitiveness and even be forced to quit the market without subsidies. Meanwhile, domestic battery producers and relevant material providers are also faced with intense competition. This trend is expected to encourage EV automakers to invest more in R&D and facilitate technological improvement.

8. Conclusions

China's energy system is undergoing a transition away from large reliance on fossil fuels toward greater dependence on clean energy sources. On the other hand, fossil fuels are likely to continue to play a significant role in both power generation and transport sectors by 2050. Particularly, coal will remain dominant in China's energy mix in the long term, especially for the power sector, and the consumption may bound back with the need for economic growth. This trend highlights the significance of the deployment of CCS technologies to ease the environmental pressure. Despite the mid-to-long-term policies made in China to control its total coal consumption, uncertainties remain regarding the peak of coal consumption. One critical challenge to bend down the coal consumption curve lies in the possibility of expanding infrastructure construction, which is likely to increase the demand for coal in the future.

On the other hand, the development of renewable energy has been considered to be one of the key solutions for China to satisfy increasing energy demand. By requiring designated electricity users to purchase an obligated quota of renewable energy certificates from renewables generators, the new renewable portfolio standard (RPS) is expected to increase China's renewables consumption and to reduce wind and solar curtailment rates. Wind energy will continue to be a focus in the long term and China aims to achieve over 210 GW of grid-connected wind energy capacity by 2020, with 5 GW of it to be offshore wind. However, bottlenecks in the grid connection and green power curtailment remain critical issues for future solar and wind power deployment.

In the short term, China is likely to continue to cut back on small-scale hydroelectric generation to address the overcapacity issue, especially as the energy demand in China is slowing down with its economic growth. Meanwhile, China is still keen for large-scale dams, which hopefully will help China to achieve its capacity goals in hydroelectricity generation. Nuclear has been a national strategic priority in China's energy transition but the future of targeted nuclear projects is not as bright as hydro primarily due to safety concerns.

Natural gas, particularly unconventional resources, will play a more important role in China's energy mix. Oil will still be dominant in the transport sector while the expanding EV market in China can help gradually phase out traditional petroleum fuels. Even without subsidies, Chinese EVs are expected to see an increase in sales by 2030, characterized by a more mature market with technological innovation, accelerated marketization, a focus on FCEV, and an advanced charging system. Despite the optimistic prospects for EVs, how to minimize the negative effects on NEV sales after subsidies exit will remain a great challenge for policymakers.

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