CHILDREN'S INVESTMENT FUND FOUNDATION

China Renewable Energy Outlook

2019

Energy Research Institute of Academy of Macroeconomic Research

“Low-carbon energy development concerns the future of humanity.”

“China attaches great importance to low-carbon energy development and actively promotes energy consumption, supply, technology and institutional transformation.

The country is ready to work with the international community to strengthen energy cooperation in all aspects, safeguard energy security, address climate change, protect the ecology and environment, promote sustainable development and bring more benefits to people around the world.”

President Xi Jinping

congratulatory letter to Taiyuan Energy Low Carbon Development Forum

October 18, 2019

Implementing Unit

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Foreword

In the 13th five-year plan, China launched the idea of an energy revolution with the aim to develop a clean, low-carbon, safe and efficient energy system towards 2050. Since then, there have be progress in a number of areas. The air in the big cities is cleaner today than five years ago, the share of coal in the energy consumption is lower, there has been a massive deployment of renewable energy, and new policy instruments like power market reforms, emission trading schemes and mandatory consumption target for renewable energy have be introduced.

However, this is only the beginning of the revolution. To reach the long-term vision of an ecological civilisation with an economic development within ecological boundaries, the efforts and pace of the energy transition must reach a new level. The benefits of a green energy transition are enormous and will enable China to continue the economic development into a moderately prosperous society with a reasonable economic growth, but it is important to realise that the transition will create both winners and losers in the short term when the energy system changes from black to green. Hence the transition process must address these challenges without losing sight of the long-term goal.

The next five years will be crucial for the energy transition. The 14th five-year plan will set the direction and pace for the transition, and China's commitment to the Paris Agreement in the coming years will be decisive for the possibilities to solve the global climate crisis. Therefore, this year's China Renewable Energy Outlook, CREO 2019, has a clear focus on the short-term actions in the context of the long-term visions for the Chinese energy system. The rapid cost reduction for solar and wind power gives basis for stepping up the deployment rate of these technologies, but a number of barriers must be removed to ensure a smooth and cost-efficient integration into the whole system.

The outlook has been prepared by ERI and CNREC, in close cooperation with national and international partners. It builds on the previous year's research and outlooks, but it is updated with the latest development and new analyses.

The research has been made possible by funding from the Children's Investment Fund Foundation and from the Danish and German governments. I would like to express my sincere gratitude to the sponsors and our partners for their support and hard work.

Wang Zhongying,

director, Energy Research Institute of China Academy of Macroeconomic Research/National Development and Reform Commission

Summary

Key Recommendations

In *China Renewable Energy Outlook 2019* (CREO 2019) the possible role for renewable energy in the Chinese energy system is analysed and the scenarios provide a consistent vision as a foundation for policy development.

- The *Stated Policies scenario* expresses the impact of a firm implementation of announced polices.
- The *Below 2 °C scenario* shows a pathway for China for building an ecological civilisation and the role China could take in the fulfilment of the Paris agreement.

This summary report provides a concise walkthrough of the main insights of CREO 2019.

The energy transition has started, but an energy revolution is needed

China has developed leading capabilities and practical experience with core scientific, technological, and industrial fields necessary for building the new system to sustain the Ecological Civilization; and it has the necessary policy blueprint for this next era.

The fossil economy, whose rapid expansion fuelled the revival of China's economy, must now be replaced by an efficient low-carbon system, tailormade to the future's requirements. As stated in the 13th five-year plan an energy revolution is needed, or more precisely an *Energy Consumption Revolution* and an *Energy Supply Revolution*.

Comprehensive energy transition to build the Ecological Civilisation

The *Energy Consumption Revolution* is an Energy Efficiency Revolution with the key feature of deep electrification. Energy efficiency is a key demand-side pillar to ensure the pace and scale of supply-side deployments are adequate to support the required economic growth. Electrification is a means to drive fossil fuels from end-use consumption, in conjunction decarbonised electricity supply.

The *Energy Supply Revolution* is a Renewable Energy Revolution, with strong emphasis on renewable electricity. Technological progress and cost reduction make renewable energy able to provide the clean energy in bulk, particularly through renewable electricity.

The 14th Five-Year Plan should accelerate the energy transition

The 14th five-year plan period 2021-2025 will be a watershed in China's energy transition history. A confluence of developments provides risks and opportunities. Many renewable energy technologies are cost-competitive and removing the subsidy element from these technologies is a necessary step in the energy transition process to stop uncertainty in the short term. Fossil fuels' external costs remain largely untaxed, and the emissions trading scheme (ETS) needs refinement to promote renewable energy over coal. The delicate process of macroeconomic adjustment could invoke traditional policy responses, reversing the energy transition.

Mismanagement of the situation risks a reversal of RE development trends and a resurgence of fossil generation and investments, acerbating technology lock-ins, more stranded assets and overshooting of China's GHG emissions vis-à-vis the Paris targets. Hence, strong and coordinated policy measures are necessary to ensure the process moves in the right direction in a cost-efficient manner.

Key recommendations for the 14th Five-Year Plan

- Set ambitious, but realistic end-targets for the period: Achieve 19% non-fossil energy by physical energy content, target a reduction of energy intensity of the real GDP by 21%, and reduce CO_2 emissions targeting a reduction of real GDP CO_2 intensity by 27%.
- Leverage the cost reductions in wind and solar and scale-up the pace of RE installations, including averaging annual additions of wind 53 GW and solar 58 GW.
- Ensure supporting RE policies, such as strong RE purchasing requirements, after the transition from subsidy to market prices.
- Internalise fossil fuels' damage and/or abatement costs through the refined ETS mechanism.
- Pursue electrification with focus on industry to reduce coal consumption and transport to stymie the growing consumption of oil products.
- Avoid new coal power plants and conduct orderly prioritised closures of inefficient plants and coal mines.

Continue the energy revolution in the next five-year plans

To reach the 2050 visions, the energy revolution must continue and further accelerate in the 15th and 16th five-year plans. CREO 2019 shows a clear roadmap for the energy system development. It is, however, too early to come up with detailed policy recommendations for these plan periods. The planning process should be carried out as an iterative process, where research and analyses give basis for policy actions, while on the other hand the development process and new opportunities in technologies and institutional settings pave way for new scenarios and research. The main imperative in the process is to stick to the long-term visions and requirements given by the Chinese leadership for the Ecological Civilisation with a clean, low-carbon, safe and efficient energy system.

China's emerging energy transition

China is in the beginning of an energy transition with the aim of building an energy system for the future. The 13th five-year plan made it clear that China should start an energy revolution and, with the important milestones for 2020, 2035 and 2050, build a "clean, low carbon, safe and efficient energy system." [1] At the 19th National Congress of the Communist Party of China, President Xi Jinping confirmed that China will promote a revolution in energy production and consumption. The country's plans emphasise shifting economic development from high growth to high-quality growth, a paradigm shift that also applies to the energy sector.

Energy consumption development

China's energy trend shows slowing growth and improving efficiency

In 2018, China's GDP grew by 6.6%, the lowest level since 1990, and primary energy consumption reached 4,640 Mtce (136 billion GJ), an increase of 3% year-on-year. Gradual improvement in energy intensity of the economy continued: energy consumption per unit of GDP decreased 3.1% in 2018, indicating an increase in energy efficiency.[2]

Coal showed second consecutive year of absolute consumption growth in 2018

Residential consumption of coal has decreased due to policies aimed at controlling emissions. Nevertheless, due to industrial consumption growth, China's coal consumption reached 3.84 billion tonnes, an increase of 1% year-on-year.[3] The proportion of coal used for power generation increased by 8% compared with 2017.[4]

China's crude oil consumption increased by 6.5% in 2018

Oil consumption reached 639 million tonnes, 3.4 times more than domestic output. Oil import dependence reached 72%, an increase of 2.4 percentage points from the prior year.

Natural gas consumption is the fastest-growing fossil energy source in China in 2018

Natural gas consumption increased by 18% in 2018, with a total volume of 282 billion cubic metres (bcm), 10 percentage points higher than natural gas production growth rate. [5] China's natural gas production reached 160 bcm. Import dependence rose to 45.3%.[6]

China's 2020 target for non-fossil energy will be achieved

Non-fossil energy consumption accounted for 14.3% in 2018, implying China's 2020 target of 15% non-fossil energy will likely be achieved ahead of schedule. [7]

Electricity consumption continued to increase.

China's total electricity consumption in 2018 reached 6,846 TWh, an 8.5% annual increase, the highest annual growth since 2012. While accounted for 57% of the total consumption growth, the growth rate was higher in services (12.7% year-on-year) and households (10.4% year-on-year) than in industry which showed 7.1% growth year-on-year.

Energy sector investment

In 2018, China's energy structure has become more diversified, and the efficiency of the whole system improved. Although coal still dominates energy consumption, this is gradually changing, and natural gas has become a new growth point for fossil fuels.

Overall investment dropped while renewable energy is still attractive

In 2018, China remained the world's largest energy investment market, although its overall sector investment dropped by 1.5% compared to 2017.[8] The investment of newly added coal-fired power plants decreased by more than 60% and energy efficiency improved by 6% in the past three years, which led to the investment decrease. In contrast, about 70% out of US$ 120 billion invested in the power sector was spent on renewable energy. [9]

Natural gas infrastructure build-out continues

Due to shortages of residential gas supplies in winter 2017, China promoted the expansion of gas pipelines and LNG import terminals in order to increase gas supply capacity.[10]

China's EV and grid-side energy storage market has continued to expand rapidly

In 2018, the sales of all passenger vehicles in China declined for the first time since 1990, while new EVs continued rapid sales growth.[11] China has ranked as the largest EV market in the world for four years running, and 2018 saw 62% of global EVs sold in China.[12]

The grid-connected energy storage sector also showed strong growth in 2018. Newly built battery energy storage facilities exceeded 600 MW, of which 36% was on the grid side.[13] Cumulative installed capacity reached 1,020 MW. [14]

Carbon and other air pollutant emissions

Carbon and major pollutant emissions intensity of production continued to decline

We estimate that CO2 emissions intensity dropped by ~2% per unit of real GDP in 2018. In China's 338 cities at or above prefecture level, ambient PM10 concentrations dropped by 5.3% and ambient PM2.5 dropped by 9.3% in 2018 versus the prior year, and the nationwide average number of haze days declined from 27.6 days in 2017 to 20.5 days in 2018. Acid rain measurements showed improvement in most Chinese regions with the lowest average frequency since 1992 when records began.[15]

New Blue-Sky Action Plan released.

The State Council issued a new three-year air pollution control plan in 2018.[16] The plan focuses on reducing the total emissions of major air pollutants, and reducing greenhouse gas emissions, particularly in the Beijing-Tianjin-Hebei region, the Yangtze River Delta region, and the Fenwei Plain (Shaanxi and Shanxi) region, reducing the concentration of PM2.5 and the number of days of heavy pollution, and improving the quality of ambient air. This is the first time to include Shaanxi and Shanxi as targeted regions.

China's national ETS marks first anniversary

China's national ETS was officially launched at the end of 2017. At the time, the schedule for establishing the ETS called for a preparation phase, followed by trial operation, and then official operation. The ETS currently remains in the preparation period.

Eight spot power market pilots have launched

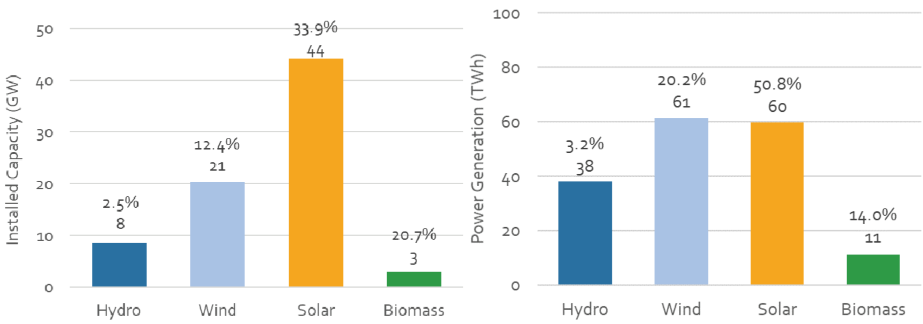
NDRC and NEA jointly announced the first batch of spot power market pilots in August 2017. These pilots covered eight regions and aimed to complete market designs by the end of 2018.[17] Almost all pilots have faced delays.

Renewable energy in China

Current progress

China has made substantial progress on scaling up renewable power as well as reducing the cost of renewable energy in the past 20 years, and as a result China has fulfilled the 13th Five-Year Plan targets ahead of time. Wind and solar PV have gradually entered the post-subsidy era, and nationwide subsidy-free and FiT tendering projects will be the new trend.

Figure 1: 2018 Incremental installed renewable capacity (left); 2018 Incremental renewable power generation (right)



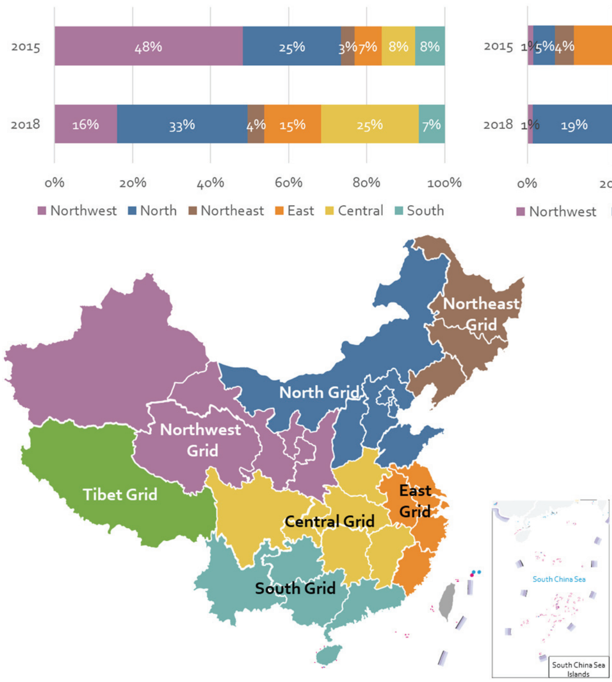
Source: Hydro data from China Electricity Council (CEC), January 2019; other data from China National Renewable Energy Centre (CNREC), March 2019

In 2018, the government promoted consumption of renewable energy via setting mandatory caps on curtailment and minimum consumption targets. Nevertheless, obstacles such as subsidy payment delays and unclear land use policies still remain. More long-term targets and measures are needed to meet the challenges and maintain healthy industrial development.

Major RE development regions shift from west to east

There has been a substantial switch in the distribution of renewable energy deployment. Historically, the resource quality was the main driver of project localisation. Increasingly, it is evident that proximity to demand, absence of curtailment reinforced by policy guidance, is determining for the geographical distribution.

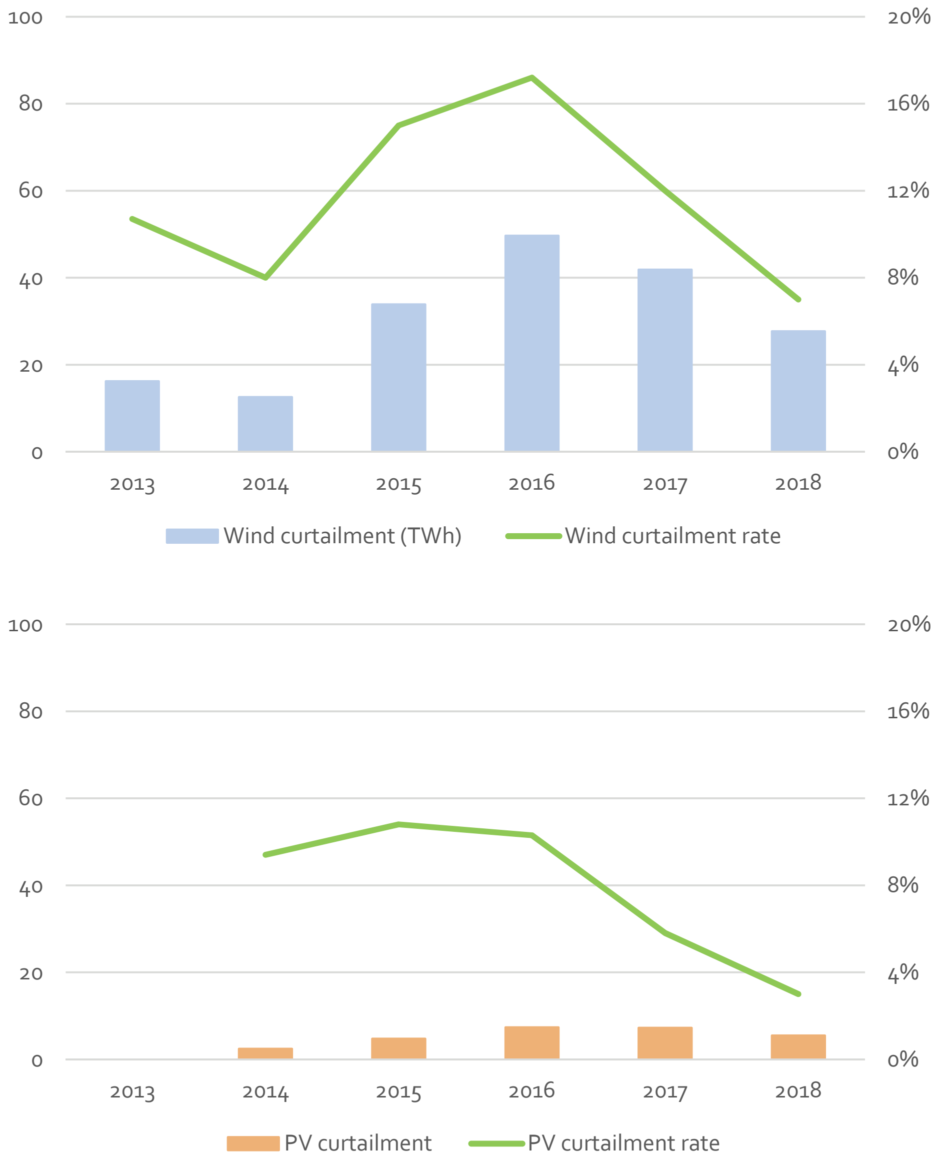
Figure 2: Regional proportion of new grid-connected wind capacity (top left) and distributed solar PV capacity (top right) in 2015 and 2018; categorization of regional power grids (bottom)



Renewable energy curtailment decreasing

In 2018, China experienced wind power curtailment of 7%, a five-percentage point improvement versus 2017. The majority of severe curtailment regions have improved: wind curtailment rates in Jilin and Gansu decreased more than 14 percentage points, while Inner Mongolia, Liaoning, Heilongjiang and Xinjiang experienced a reduction of more than five percentage points. China saw solar power curtailment of 3%, 2.8 percentage points less than in 2017. Xinjiang and Gansu saw the most improvement: solar curtailment rate decreased by 6 percentage points and 10 percentage points. Officials cited high renewable energy capacity, large scale thermal power plants and lack of transmission capacity as the main causes of high curtailment.

Figure 3: China 2018 curtailment of wind (top) and solar PV (bottom)

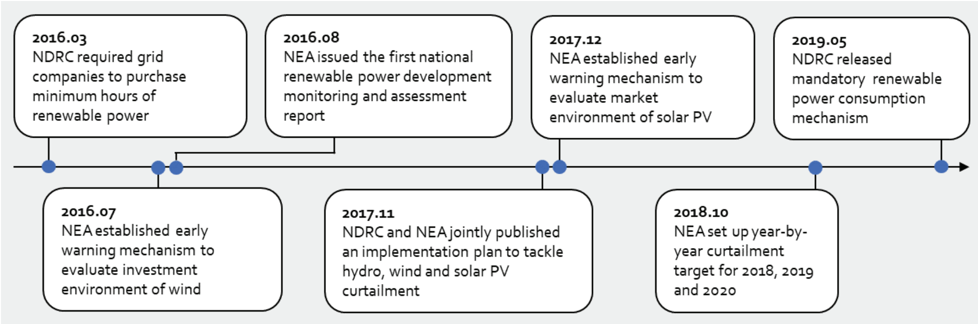


Source: China National Energy Administration, February 2019

In 2018 and 2019 a number of policy measures have been launched to promote the deployment of renewable energy. As part of a three-year clean energy consumption action plan, aims to substantially reduce the curtailment of wind and solar with a more focused deployment plan and by promoting on interprovincial exchange of renewable energy.

Also, a mandatory renewable energy consumption mechanism has been launched, with quotas for each province, requiring power retailers and end-users to increase renewable power consumption.

Figure 4: Development of polies for renewable energy consumption



Source: NEA and National Development and Reform Commission (NDRC), accessed in July 2019

Wind and solar are almost competitive with coal

The rapid scale-up of wind and solar in China and worldwide has reduced costs for these technologies. The cost of wind power is around RMB 0.5/kWh in regions with typical wind conditions, down to RMB 0.35/kWh in the windiest regions. Solar PV has achieved the 2020 target of price competitiveness with the retail electricity price in 2018 and LCOE has declined to approximately RMB 0.37-0.51/kWh.

China has begun to shift from fixed feed-in tariffs to tendering and subsidy-free renewables

For new wind and solar power projects, tenders will gradually replace feed-in tariffs. The feed-in tariffs have been capped for solar power with a limit for the total subsidy amount. Besides the subsidised deployment, NEA and NDRC encourage the deployment of subsidy free wind and solar projects. These projects receive special attention regarding removal of barriers and there are no capacity limits for these projects.

Besides these direct supporting mechanisms, distributed renewable energy project are also encouraged to participate in the various power markets.

Major challenges for RE in China

Despite these new policies, renewable energy development has encountered setbacks at the national, regional, and individual levels. On the national level, the implementation of the mandatory consumption mechanism remains unclear. The lack of flexible resources, up-to-date energy and power systems planning, renewable electricity consumption has become a long-standing challenge. Subsidy payment delays, interference in market trading and pricing by local governments, and increasing soft costs all bring risks for renewable projects. More long-term targets and measures are needed to meet the challenges and maintain healthy industrial development.

Energy scenarios for China's energy transition

CREO 2019 continues the tradition from previous outlooks by defining two core scenarios for the energy systems development. The scenarios provide a clear and consistent vision for the long-term development as basis for short-term decisions

Ecological civilisation fuelled by clean, low-carbon, safe and efficient energy

The *Stated Policies scenario* expresses the impact of a firm implementation of announced polices, while the *Below 2 °C scenario* shows a pathway for China to achieve the ambitious vision for an ecological civilisation and the role China could take in the fulfilment of the Paris agreement.

Scenarios' strategy

Economic growth is a bottom-line precondition of China's socioeconomic objectives for 2050. It is required that GDP grows 4.2 times from 2018 level in real terms by 2050. However, the growth shall be sustainable and supported by the transition of the Chinese energy system – an essential component in the efforts to build China's Ecological Civilisation.

The strategy for the energy transition explored in CREO 2019 relies on three pillars:

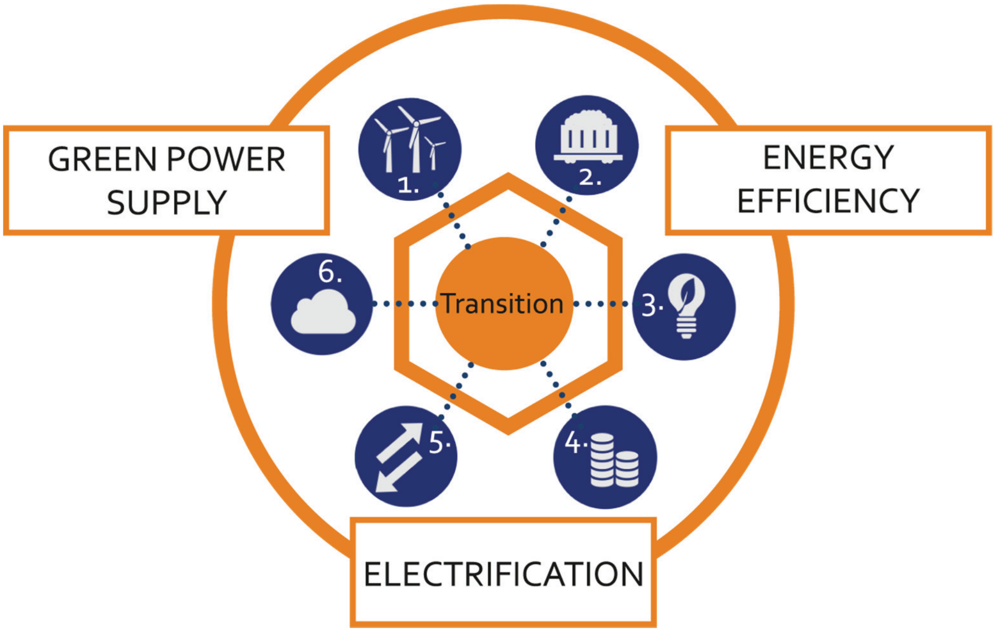
- **Energy efficiency** is a key demand-side pillar to ensure the pace and scale of supply-side deployments are adequate to support the required economic growth.
- **Electrification** and market reforms will change the rules of the game and drive fossil fuels from end-use consumption, in conjunction decarbonised electricity supply.
- **Green energy supply –** technological progress and cost reduction makes RE able to provide the clean energy in bulk, particularly through renewable electricity.

The strategy is supported by key drivers:

1. **RE promotion:** Supporting frameworks must ensure continued development, as subsidies are phased out.
2. **Coal control:** Coal is the main culprit of China's environmental challenges and greenhouse gas emissions, requiring firm control of both production and consumption.
3. **Energy efficiency measures:** Energy efficiency potentials in China's energy system are profound but must be supported by strong policy. This goes hand in hand with the restructuring of the economy towards less energy intensive sectors.
4. **Power markets:** Power market reforms shall deliver significant efficiency gains, enabling electricity to be a cost-competitive energy carrier for more consumption applications. Increased variable generation makes dynamic short-term power markets important for motivating comprehensive balancing participation.

5. **Flexible power system:** Variable generation will become the crux of the power system, and flexibility services a prerequisite. Cost-efficient transition requires using all cost-effective sources including generation, demand, grid and storage.
6. **Efficient carbon control policy:** Pricing and control of carbon emissions is promised to be guided by market forces under the national emissions trading system being piloted in the power sector, to be further expanded to all main emitting sectors.

Figure 5: Drivers of the energy transition in the scenarios



Stated Policies scenario expresses firm implementation of announced policies

The scenario assumes full and firm implementation of energy sector and related policies expressed in the *13th Five-Year Plan* and in the *19th Party Congress announcements*. Central priorities are the efforts to build a clean, low-carbon, safe and efficient energy supply. The scenario also includes the *NDC* climate target to peak in emissions before 2030, the effects of the *Blue-Sky Protection Plan*, aspects of the *Energy Production and Consumption Revolution Strategy*, and the *National Emissions Trading scheme*.

Policy trends are extrapolated to set the longer-term policy drivers.

CNREC's energy system modelling tool

The scenario's development in CREO is supported by CNREC's energy system modelling tool, consisting of interlinked models, covering the energy sector of Mainland China.

Final energy demands are directed in the END-USE model

The END-USE model, based on Long-range Energy Alternatives Planning system, LEAP (https://energycommunity.org/) represents bottom-up models of end-use demand and how this demand is satisfied. End-uses are driven by assumed developments in key activity levels specified for each subsector and the economic value added for where no other driver is available. These drivers translate to energy consumption when combined with assumptions, as well as end-use behavioural features adjustment. Transformation and resource activities aside from district heating and power are also covered by LEAP, including upstream refinery activity.

Power and district heating sectors are modelled in EDO

The EDO (Electricity and District heating Optimisation) model is a fundamental model of power and district heating systems, built on the Balmorel model (www.balmorel.com). The power system is represented at provincial level, considering the interprovincial grid constraints and expansion options. The model includes thermal power (including CHP), wind, solar (including CSP), hydro, power storage, heat boilers, heat storages, heat pumps, etc. It also considers demand-side flexibility from industries, options for charging of electric vehicles and the option of a full integrated coupling with the district heating sector.

The model can represent the current dispatch in the Chinese power system on an hourly basis, including technical limitations on the thermal power plants and interprovincial exchange of power; as well as the dispatch in a power market, provincial, regional or national, based on the least-cost marginal price optimization. Key characteristics relate to the detailed representation of variability of load and supply (e.g. from VRE sources) as well as flexibility and flexibility potentials, which can operate optimally and be deployed efficiently in capacity expansion mode.

Combined summary tool

Results from the two models are combined in an integrated Excel-based tool, which provides an overall view of the energy system, combining fuel consumption from the power and heating systems from EDO, with direct consumption in end-use sectors and other transformation sectors from LEAP.

Below 2 °C scenario shows how China can build an energy system for the ecological civilisation

The main driver is a hard target for energy related CO_2 emissions through a strategy with renewable electricity, electrification and sectoral transformation at the core. The cap is set at 200 million tons of energy related CO_2 emissions in total between 2018-2050.

Main assumptions in the Below 2 °C scenario

- Population of 1.38 bn in 2050.
- GDP increased 4.2 times in real terms to RMB 380 trillion by 2050.
- Urbanisation rate of 78% by 2050
- Primary energy consumption stable after 2030 below 6 bn tce.
- Coal consumption restricted to 1 billion tons of coal (714 billion tce) by 2050.
- Natural gas to peak in 2040 in the range 580-600 bcm
- Diversified supply with significantly reduced dependence on imported fuels.
- Energy intensity shall be reduced by 85% relative to 2018.
- Non-fossil energy to cover 2/3 of primary energy.
- CO_2 emission 2018-2050 below 200 billion tons cumulative, and 2050 emissions less than 2500 million tons.
- Electrification rate above 60%

The Stated Policies scenario adopts a similar pathway, but with a less ambition electrification target (50%) and without a strict CO_2 boundary.

Overview of the 2050 Energy System – The Below 2 °C scenario

In CREO, the main scenario is the Below 2 °C scenario, since the scenario comply with all long-term goal to build a clean, low-carbon, safe and efficient energy system. Furthermore, China's contribution is essential for global efforts to comply with the temperature objectives of the Paris agreement. Hence, emphasis for the Chinese energy transition should be on the Below 2 °C scenario for a Low Carbon Energy system compliant with Paris objective.

In the following the main results from the Below 2 °C scenario in the medium- and long-term are presented and explained.

Table 1: Key result for the energy sector development in the Below 2 °C scenario

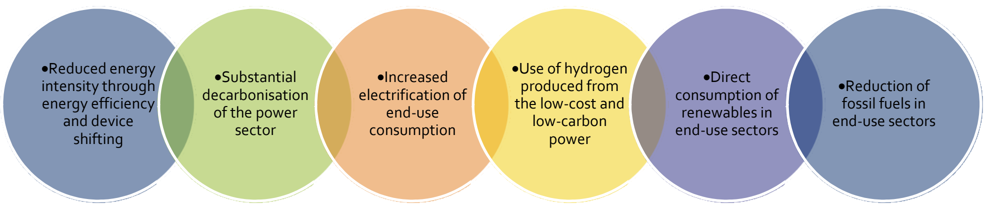
		2018	2020	2025	2030	2035	2050
Energy basis							
Total Primary Energy Supply (TPES)	Mtce	4 346	4 476	4 610	4 432	4 025	3 536
Total Final energy consumption (TFEC)	Mtce	3 165	3 252	3 396	3 438	3 349	3 046
CO_2 emission	Mton	9 525	9 337	8 804	7 184	5 079	2 532
Non-fossil fuel share of TPES (NFF)	%	10%	14%	19%	29%	42%	65%
RE share of TPES	%	8%	11%	16%	25%	37%	58%
Coal share of TPES	%	61%	56%	47%	36%	23%	11%
Coal share of TFEC	%	33%	29%	20%	14%	10%	4%
Gas share of TPES	%	8%	10%	13%	15%	18%	16%
Oil share of TPES	%	20%	20%	21%	19%	16%	7%
Electrification rate	%	26%	29%	35%	41%	48%	66%
Coal substitution method							
Total Primary Energy Supply (TPES)	Mtce	4 684	4 891	5 253	5 549	5 603	5 766
Non-fossil fuel share of TPES (NFF)	%	17%	21%	29%	44%	59%	79%
RE share of TPES	%	15%	18%	26%	40%	55%	74%

Energy CO2 emissions reduced 45% by 2035 and 75% by 2050 from 2018

The 2018 level of 9,550 million tons of annually energy related CO2 emissions is reduced to 5,150 million tons by 2035 and 2,600 million tons by 2050. The scenario has approximately 195 billion tons of accumulated CO2-emissions in the period 2018 – 2050, a pathway for China, which significantly and responsibly contributes to the global emission reduction effort.

The CO2 emission reductions are realised through multiple measures as shown in Figure 6.

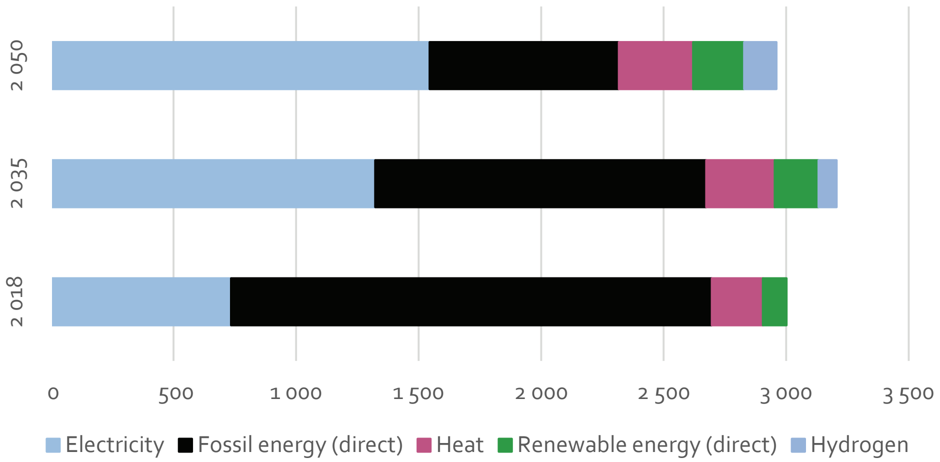
Figure 6: Measures to reduce CO_2 emissions for the Chinese energy system



Final energy consumption stabilises at current levels

Energy savings, device shifting, and economic restructuring, enables the 2050 total final energy consumption to be slightly below its 2018 level, at 3,050 Mtce/year. Until 2035, the final energy consumption increases to around 3,350 Mtce/year.

Figure 7: Final energy consumption by energy carrier in the Below 2 °C scenario (Mtce)

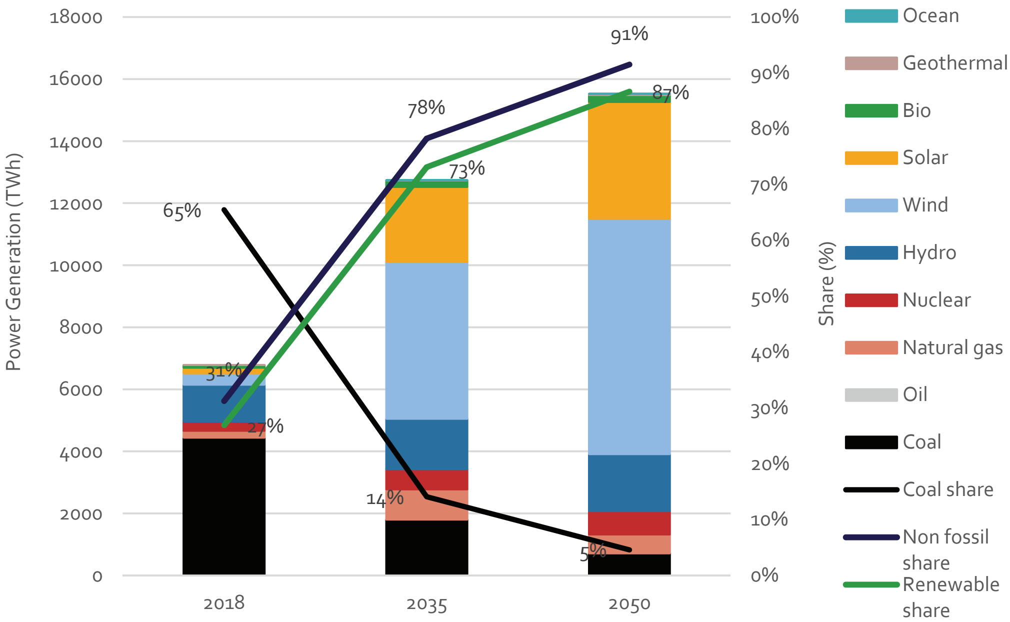


The energy transition is thereby able to support the targeted economic expansion without a long-term increase in final energy consumption, partly as consequence of the changes in economic structure, partly by improvements in energy efficiency of devices and production measures, as well as shifting away from direct use and combustion of fossil-fuels towards consumption of electricity.

Electricity is decarbonised with 78% non-fossil electricity by 2035 and 91% in 2050

This presupposes firm implementation of key policies including the ongoing power market reform and an efficient CO2 ETS mechanism, ensuring a competitive level playing field for renewable electricity. Wind and solar account for the lion's share of this transition, with 58% of the total electricity generation by 2035 and 73% by 2050.

Figure 8: Power generation mix in the Below 2 °C scenario

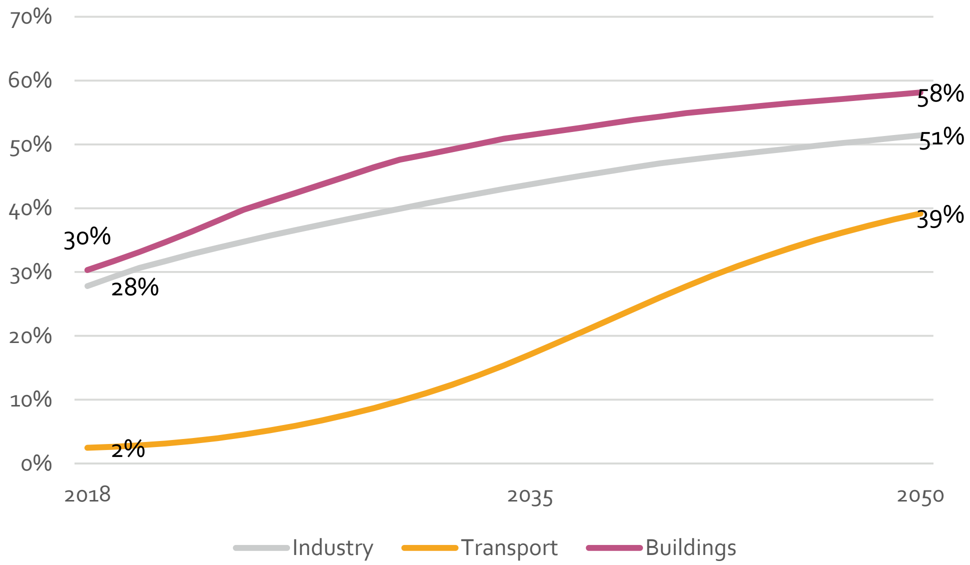


Electrification enhances the reach of decarbonised electricity supply

The IEA (2018) states in that "*A doubling of electricity demand in developing economies, puts cleaner, universally available and affordable electricity at the centre of strategies for economic development and emissions reductions.*" [18] Due to the cost-reductions in renewable electricity supply sources, electricity becomes an increasingly cost-competitive energy carrier and thereby a means to replace direct consumption of fossil fuels.

The electrification rate increases from approximately 26% in 2018 to 48% by 2035[19] to 66% by 2050. By 2050, transport sector has reached 39% electrification in the Below 2 °C scenario, from 2% in 2018. Industry has increased from 28% to 51% and buildings from 30% to 58%.

Figure 9: Development of electrification rate in transport, industry and buildings



Hydrogen offers feasible ways to expand the use of renewable electricity

The use of hydrogen produced by electricity is expanded in long-haul transport (as fuel), chemicals (as feedstock), and iron and steel (replacing coke). The share of hydrogen in the final energy consumption reaches 2.3% in 2035 and 4.5% in 2050, adding respectively 1,047 TWh and 1,536 TWh of electricity consumption.

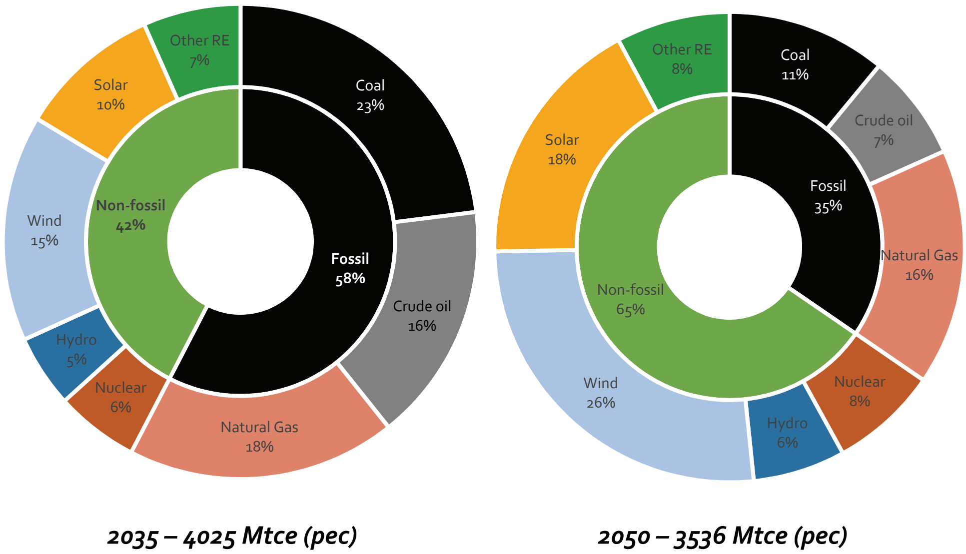
The heating system and the central role of district heating

Heat consumption in buildings grows from around 4,500 TWh/year in 2020 to around 5,900 TWh in 2050, with the consumption stabilising around 2035. Until 2050 district heating satisfies a stable ~50% of heating demand. Electric boilers, heat pumps and heat storages are deployed to scale, and deliver much needed flexibility to the power system. District heating and better-insulated buildings are main sources of building energy conservation.

Primary energy consumption mix is diversified as low-carbon sources replace coal

By 2035, coal's contribution towards primary energy consumption has been reduced by 62% and further by 82% in by 2050. Coal's share is reduced from approximately 61% 2018 to 11% 2050[20]. Natural gas' contribution to primary energy expands considerably from around 8% in 2018 to 18% in 2035 and 16% in 2050. Oil's contribution is reduced from 20% in 2018 to 16% and 7% in 2035 and 2050.

Figure 10: Primary energy mix after two coming eras of transformation (Below 2°C)



Non-fossil energy accounts for 42% by 2035 and 65% by 2050

By the coal substitution method of primary energy accounting, the non-fossil energy proportion becomes 47% and 59% in the two scenarios respectively. Thus by 2035, the non-fossil energy proportion would far exceed the official policy target of 20% by 2030, just five years later. **It is apparent, that the official 2030 target should be increased as part of the Government of China's goal setting in the 14th five-year plan.**

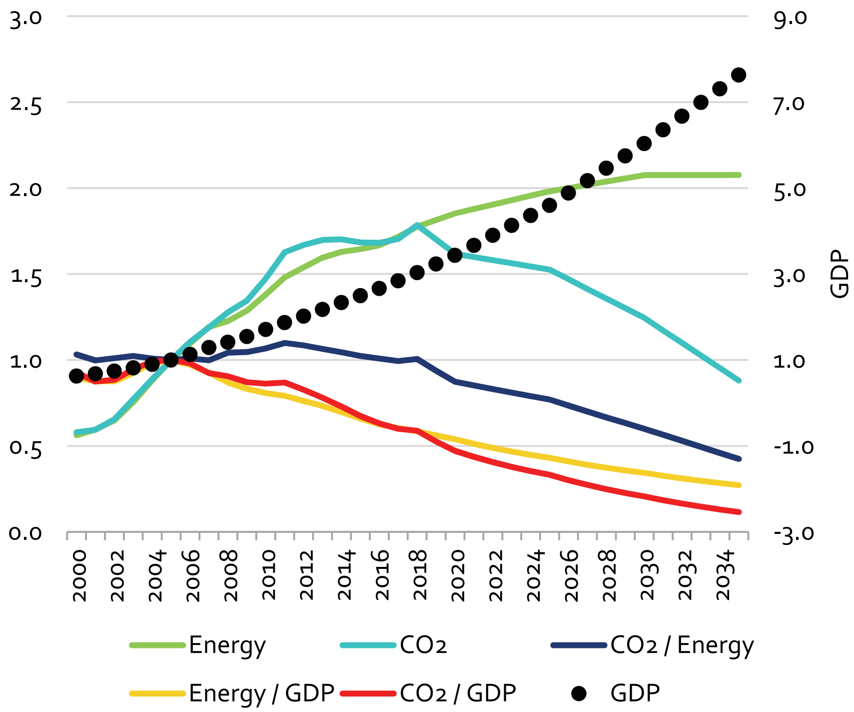
Roadmap for Energy Transition

The *Energy Consumption Revolution* is an Energy Efficiency Revolution with the key feature of deep electrification. The *Energy Supply Revolution* is a Renewable Energy Revolution, with strong emphasis on renewable electricity. Renewable electricity is the most cost-effective large-scale decarbonisation approach. To ensure that renewable electricity by 2035 is at the core of the energy system steps the 14th, 15th and 16th five-year plans are crucial.

Sustainable economic growth while building the ecological civilization

During the 14th FYP is expected to grow the economy by 34% in real terms from 2020-2025. Meanwhile, coal consumption declines by 11%, the War on pollution must be won, primary energy consumption growth should be limited to 6% (8% by coal substitution). Energy consumption intensity of the economy should be reduced by 19% and energy CO_2 intensity should be reduced by 27% - a total reduction of CO_2 intensity of 66% relative to 2005.

Figure 11: Kaya identity in the Below 2 °C scenario relative to 2005



The subsequent 15th and 16th FYP should grow the economy by 31% and further 26%, respectively. Energy consumption intensity should be further reduced by 20% and 21% in the 15th and 16th FYP respectively. Meanwhile, CO_2 intensity of real economic growth should be reduced by 31% and 36% in the 15th and 16th FYP.

Figure 12: Shift in primary energy consumption mix during 14th FYP (Below 2°C)

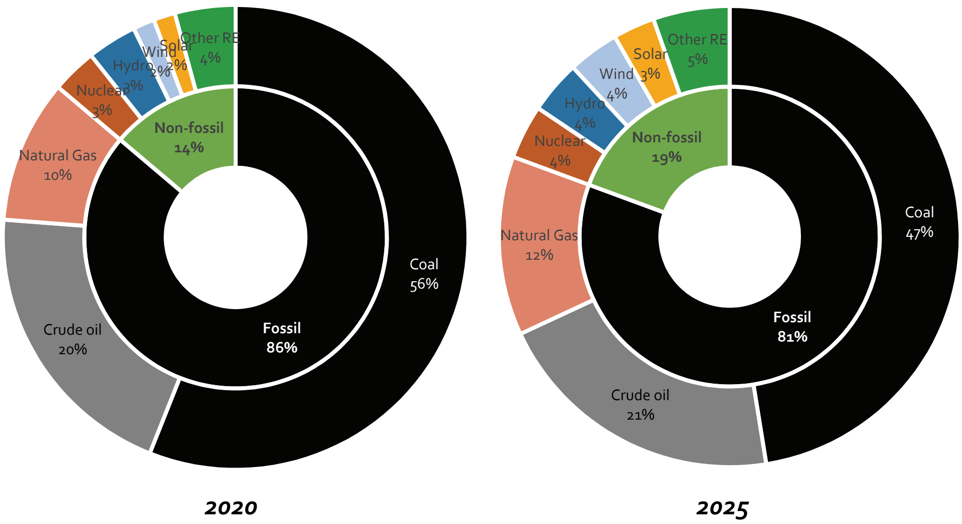
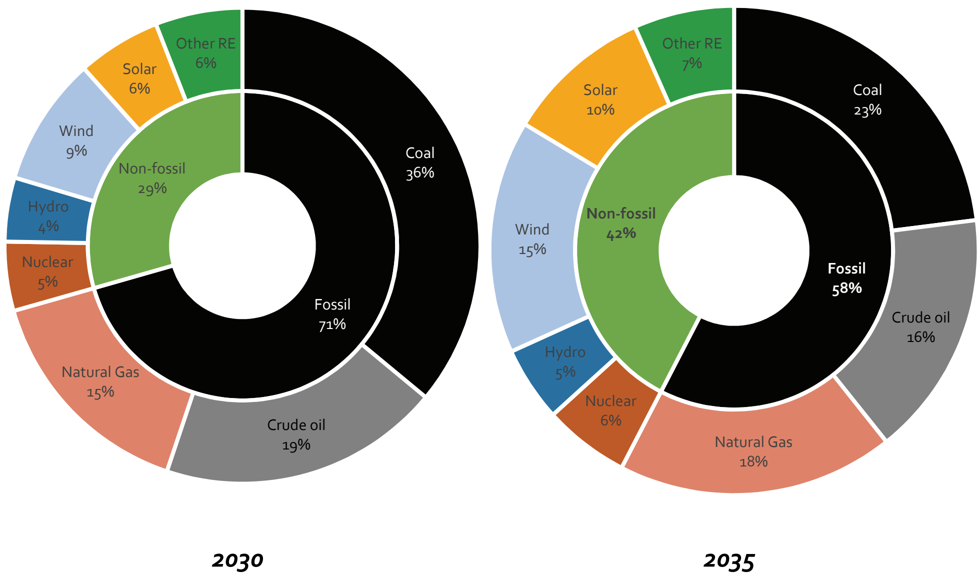


Figure 13: Further switch in primary energy mix during 15th and 16th FYP (Below 2°C)



Note: Figure shows primary energy mix in terms of statistical energy content method

Clear capacity targets for renewable power development

While the cost of wind power and photovoltaic keeps decreasing in 14-FYP period, some projects still depend on subsidies from the government. It is important to maintain annual additional capacity targets for the projects, so that a level of industrial scale of equipment suppliers and construction ability can be maintained while the total amount of subsidy can be limited to an affordable level.

Renewable electricity deployment the next 3 five-year plans must a pattern of three steps:

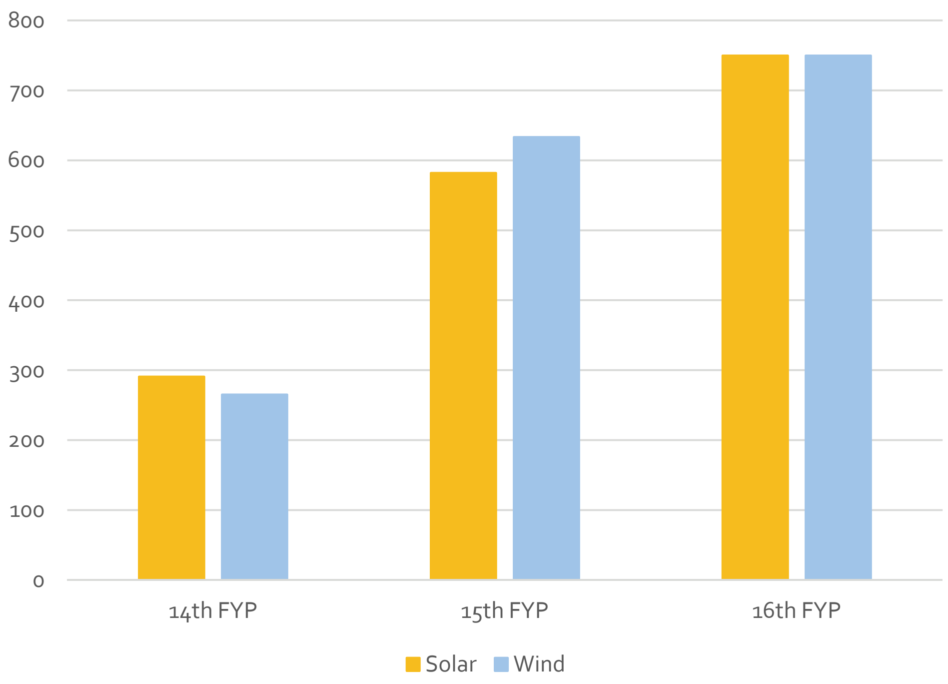
14th FYP – Industry scale-up: average annual additions of wind 53 GW and solar 58 GW

15th FYP – Establish: Wind averages 127 GW and solar 116 GW annually.

16th FYP – Revolutionise: ~150 GW per year of wind and solar

For the power sector decarbonisation, the critical targets to be achieved by 2025, is that wind power cumulative installed capacity exceeds 500 GW, contributing with potential annual generation of approximately 1350 TWh of electricity. Moreover, solar power cumulated installed capacity should reach 530 GW, and contributed with electricity generation of around 690 TWh.

Figure 14: Wind and solar installations under by five-year-plans



The 14th FYP period will be a critical phase for renewable energy installations, where in tandem with scaling-up the industry and annual deployment levels, investors and asset owners must learn to navigate the uncertainties of simultaneous reforms.

- RE investments must wean off the comfortable business model of fixed price subsidies and navigate the emergence of spot-markets as well as medium- to long-term contracting markets as these are developed.
- Investors and asset owners shall have confidence that they are able to capture adequate prices for their electricity generation, and that they will not be curtailed, while being exposed to the market. There must be evidence that system flexibility develops as needed; alternatively, they must develop more complex business models bundling VRE sources with own investments in flexibility and storage.
- The market must respond timely to the development of the demand for green, clean or non-fossil electricity – the pull from demand and the requirements from regulation. Finally, there must be confidence that, despite a slowing energy consumption growth resulting from energy efficiency and economic restructuring, there will be increased electrification, and that the authorities will abstain distorting the markets by supporting competing power offerings from coal and gas and depress the prices.

The 14th FYP should give priority to developing capacity and balancing capability near consumption centres, including giving focus on wind offshore developing, opening for more distributed siting of wind, and improving conditions for DGPV.

Table 2: Suggested targets for 14th, 15th and 16th FYP period based on the Below 2 °C scenario

Category	Indicator	14th	15th	16th
1. Renewable power generation capacity target (GW)	**Total**	**1481**	**2.718**	**4.108**
	1. Hydropower	386	438	455
	2. Wind power	507	1.109	1.763
	3. Solar photovoltaic	532	1.109	1.825
	4. Solar thermal power generation	4	9	11
	5. Biomass power generation	51	54	54
2. Renewable electricity generation target (TWh)	**Total**	**3662**	**6.416**	**9.308**
	1. Hydropower	1397	1.576	1.625
	2. Wind power	1347	3.160	5.053
	3. Solar photovoltaic	694	1.448	2.393
	4. Solar thermal power generation	11	22	28
	5. Biomass power generation	214	210	210

In the 15th FYP, the pace of RE capacity additions moves towards the peak, while growth rates in power consumption, drops to 3.5% p.a. on average. The 15th FYP must thread the needle of building the capacity for a long-term sustainable renewable energy industry.

The 16th FYP will be the period of disruptive transformation. We are past the economic tipping points with significant impact to asset utilisations. Wind and solar annual installations should reach their peak at around ~150 GW/year and new electricity storage should be coming online at the pace of 30 GW per year. Utilisation rates of fossil-thermal plants shall decline significantly, and strategic plant closures should be considered.

Developing a coupled energy system with electrification as the crux

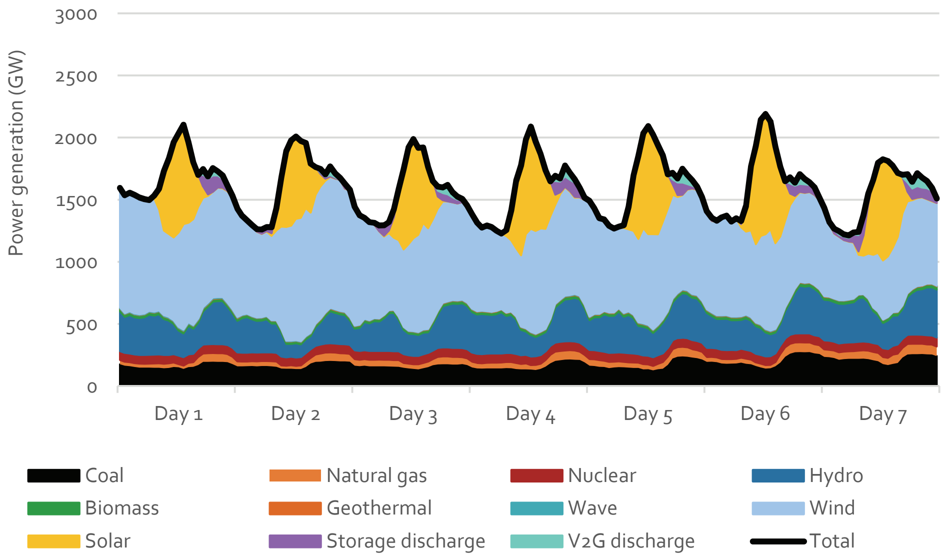
Electrification plus renewables can economically displace fossil fuel consumption in other sectors. Meanwhile, the consuming sectors shall be developed to further support the electricity sector in maintaining the system balance cost effectively through provision of flexibility.

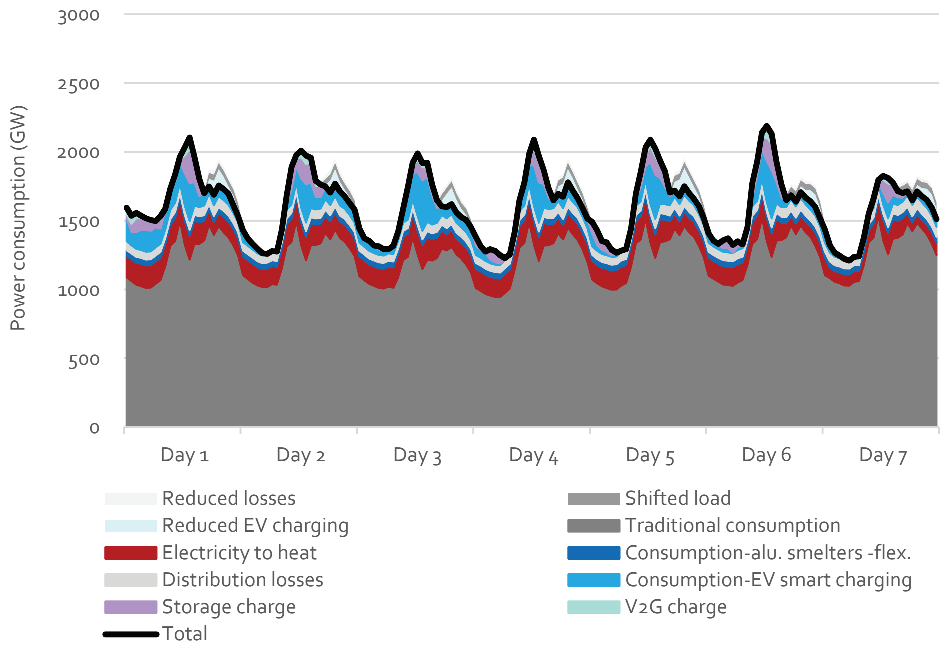
The 14th FYP should include targets and measures to support technologies an incentive to unleash the benefits of an efficient power and district heating coupling. The stock of individual heat pumps should be increasing and displace individual coal boilers and stoves. The number of EVs should increase to almost 33 million by 2025, and around 14% of the vehicle stock should be new energy vehicles (NEVS) including electric, hydrogen and plugin hybrids. For EVs, this shall be accompanied by charging infrastructure, with around 1 normal charging stations for every 10 EV's and around 1 fast charging stations per 100 EVs. Programmes and/or retail tariffs for EV charging should expose users to changing prices, such that smart charging is motivated.

Electrification should move to exceed 42% of the final energy consumption in industry, and industries should be exposed to fluctuating market prices, and motivated towards providing cost-efficient demand respond. Key energy intensive industries should be at the forefront. Scrap-based electric arc furnace steel should reach 30-32% by 2025.

By the end of the 16th FYP, the penetration levels of variable renewable energy will be high, and the availability of traditional thermal assets for maintaining the system balance including ancillary services shall reduce. Smart energy services, demand response from industrial and residential loads and electric vehicles must be deployed at scale. The district heating sector has achieved the tipping point, where large-scale replacements of thermal heating capacity, including CHPs are being replaced/supplemented by power-to-heat technologies. The energy internet becomes a reality, with data and digitisation supporting the timing, scheduling, adjustments and power based on a comprehensive system of data on loads, prices, assets locations. This becomes possible with the introduction of smart meters as well as home energy management systems, etc.

Figure 15: Example of supply (top) and demand (bottom) side dispatch and flexibility in 2035.





Strengthened energy efficiency targets needed for the next era

The importance of energy efficiency in the energy transition cannot be overstated. The rapid pace required for scaling-up clean energy investments on the supply side is only sufficient, given that energy consumption is significantly decoupled from the economic growth targets.

In the 14th FYP energy efficiency measures must be defined such that the primary energy consumption per unit of GDP should decline by at least 19%. The measures shall support the transitioning of consumption from their current energy carriers towards electricity. Final energy consumption should remain below 3400 Mtce/year and primary energy consumption not grow above 4610 Mtce.

Energy efficiency shall take place both in the point of energy use and in the supply-chain. It can be achieved through better insulation and technology improvement in buildings (e.g., electric heaters will reach an efficiency of 98.1% by 16th FYP) as well as the promotion of efficient processes in industry (e.g., in steelmaking, EAF process will contribute up to 29% in steelmaking production by 16th FYP). Furthermore, the energy efficiency benefit of renewables should be recognized in setting targets for primary energy consumption. Until 2035, the final energy consumption increases to around 3,350 Mtce/year, while primary energy consumption should be contained below 4025 Mtce/year.

Strict coal controls to halve consumption by 2035

While in the long run, the expanded national ETS system could be the preferred mode of coal and carbon containment, administrative measures are needed in the short-term.

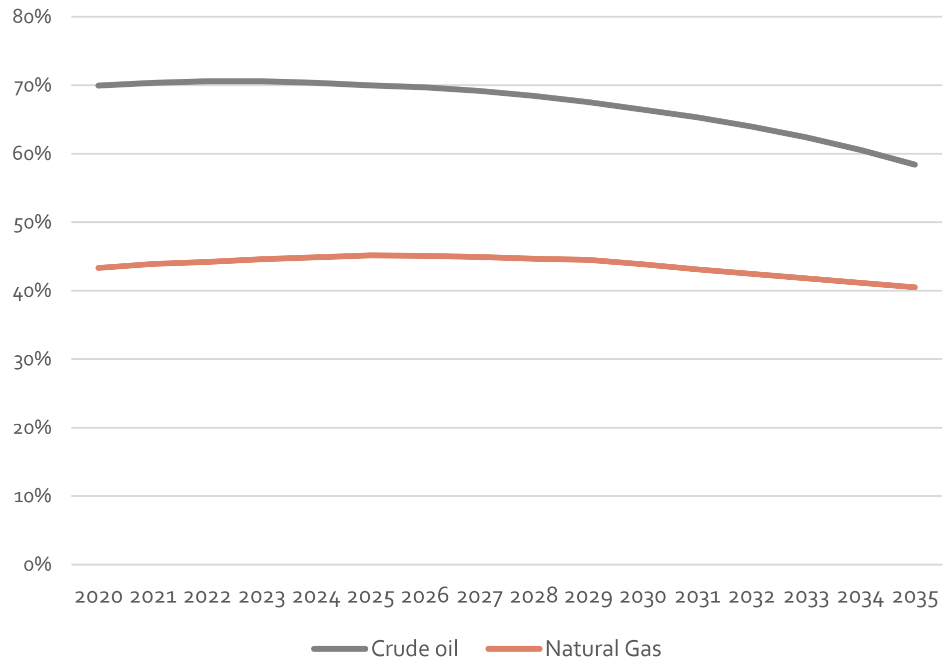
In the 14th FYP, the coal consumption should be reduced by 10%. The 15th FYP should implement further 24% reduction, and in the 16th five-year plan period the reduction should be 37%. Thereby the coal share of primary energy consumption is reduced to 47%, 36% and 23% by the end of the 14th, 15th and 16th five-year plans respectively. Preserving energy security by the energy transition

The energy transition must ensure that safe and stable energy fuels the economy in the next era of economic development. The rapid growth of oil consumption is potentially destabilising, as oil imports have been accounting for increasing percentages of the country's supply. While oil and gas imports will increase in absolute terms during the 14th five-year plan by at least 8%, the import percentage of oil can be stabilised.

The efforts to expand indigenous natural gas supplies are merited and necessary, provided that environmental safeguards are forcefully upheld. China must avoid the economy is significantly dependent on imported foreign fuel. Natural gas imports, which grow by almost 70%, see an estimated increase in the import share by at least 6 %-points during the 14th five-year plan. Hereafter, the by a combination of increased domestic production and a slowdown in growth of gas consumption in favour of other clean energy sources, implies that the import share of natural gas can decline in the 15th FYP.

By 2035, the import share of oil and natural gas can be lower than today, as a result of the energy transition.

Figure 16: Import shares of fossil fuels in the Below 2 °C scenario



Breaking the curve of energy related CO2-emissions

Despite an uncertain, and at times tense, geopolitical environment, there is strong active cooperation on energy and climate issues, which benefits all parties.

Carbon intensity levels should be reduced in the 14th five-year plan by 27% to 67 g/RMB – a cumulative reduction of 66% since 2005 (in real terms).

In the 14th five-year plan, the carbon market should be reformed to include self-adjusting mechanisms, such as a flexible cap, floor price, and stability reserve, to prevent a collapse in carbon prices leading to undesired investment signals in favour of high-carbon investments. The carbon quota allocation scheme must be adjusted to not provide indirect subsidy for (efficient) coal-fired generation over clean energy sources.

Policy emphasis in the 14th Five-Year Plan

The 14th five-year plan period 2021-2025 will be a watershed in China's energy transition history. A confluence of developments provides risks and opportunities. It is critical that policy guidance is consistent and that measures ensure policy continuity during a period of upheaval and policy driven energy revolution.

Ambitious, but realistic end-targets for the period should be set

Achieve 19% non-fossil energy (by physical energy content), target a reduction of energy intensity of the real GDP by 21%, reduce CO_2 emissions targeting a reduction of real GDP CO_2 intensity by 27%, reduce coal consumption by 11%.

Clear guidance for power sector needed in 14th Five-Year Plan period

Conduct integrated long-term planning

Given the boundary conditions, such as national targets of non-fossil fuel energy and electricity consumption growth predictions, a proper planning model and a standard planning procedure should help evaluating and coordinating the development of infrastructure, power sources, and flexibility investments. With a clear long-term vision, potential risks and uncertainties can be examined through the model and reduced by improving the policy framework. By fitting into the long-term strategy, short-term targets can better facilitate the long-term visions to yearly action plans without adverse impacts from short-term incidents. An integrated long-term planning process will become increasingly important when administrative approval procedures are replaced by power markets driven incentives. Experiences from the European integrated planning processes could be inspiration for a planning process in a Chinese context.

Give priority focus to power system flexibility

Flexibility is an essential element for the successful integration of renewable electricity in the power system. It is important that the policy design promotes flexibility. The power market should facilitate flexibility services for existing flexible sources to be discovered and better utilized. Compensation through reservation of flexible sources should attract investments in flexibility and to maintain a stable level of flexible capacity.

As fossil-fuel plants face increasingly face insufficient operating hours they should have focus on providing flexibility, and inefficient and unclean plants should be phased out in an orderly manner.

Continue to foster good market environment for renewable integration

It is important to continue to complete and consolidate existing spot markets and focus on mobilizing flexible sources in current power system to better integrate renewable energy, including transmission, thermal and hydro power plants, industrial demand response and storage. Better use of the Mandatory Renewable Electricity Consumption Mechanism[21] is key to ensure the renewable share in electricity consumption and to motivate consumption of renewable energy. The national carbon market must be enhanced and expanded to better reflect the external cost of emissions. Furthermore, an effective administrative monitoring system during the power sector reform process should be established to maintain the market rules.

Development of wind and solar requires improved grid integration and uptake of RE

To enable healthy wind and solar development, grid companies and third-party organizations should be required to annually publish five-year electricity demand forecasts, including forecasts for absorption of new wind and solar output, establish a mechanism for regularly publishing forecast results, and use this as the basis for wind and PV development and policies. The market should guide the timing and location of new wind and solar projects via competitive allocation of construction quotas. When China's wholesale power markets mature, wind and PV additions will more depend on market forces.

As wind and solar become increasingly competitive with coal, policymakers may temporary need to limit annual wind and PV additions in specific regions to prevent new grid bottlenecks. Policymakers must manage the risk of stop-go situations in renewables investments market and industry. Policies must prevent grid and market constraints on renewable development, ensuring bottlenecks do not lead to a collapse of the renewable energy industry. Policy must support China's transition to clean energy, ensure the sound development of manufacturing industry, while also ensuring integration of electricity demand and absorption of renewable output.

Adding new coal power capacity should be avoided

Adding new coal power capacity, with a lifetime of 40 years or more, would be counterproductive for the energy transition, introducing risks for stranded investments in a competitive power market. Investments in new coal capacity should be avoided or limited as much as possible. The institutional mechanisms for accelerating a smooth retirement of old and inefficient coal plant needs to be put in place. Limiting the share of coal in the electricity generation mix is critical for the reduction CO2 emission and structural enhancement of power supply, especially during 14-FYP, when renewable energies' cost-competitiveness is just emerging, and the carbon price incentive is weak.

The 14th Five-Year Plan is key to reform of renewable energy policy

Early in the 14th Five-Year Plan period, the feed-in tariffs for onshore wind and PV generation will be withdrawn since these have become mature industries with rapid market development and large-scale manufacturing.

Industry expects PV costs on par with coal power early in the 14^{th} Five Year Plan

In 2019, the weighted average difference between the tariffs for coal-fired power generation and onshore wind is RMB 0.1/kWh and RMB 0.14/kWh for PV, and the feed-in tariff for new onshore wind projects will be completely withdrawn by 2021. In 2019, the average subsidy level of PV auction projects is only RMB 0.065/kWh.

New policies will support renewable energy and guide the RE industry's development.

After a decade of feed-in tariff and subsidy compensation to support the renewable energy deployment, policy supports will shift during the 14th Five-Year Plan period. Even though the subsidy for onshore wind power and photovoltaic power will phased out in 14-FYP, new mechanisms and regulations are necessary to continue to drive the cost down, by improving the investment and utilisation environment as well as enhancing regulations and monitoring systems.

New support policies will continue to both support prior renewable energy deployment and operation, as well as guiding the renewable energy industry's development. These changes coincide with wholesale power market reform, for which the 14th Five-Year Plan period will be critical. The challenges of regulatory transformation are, multifaceted and uncertain in terms of their design and implication from the support of renewable energy.

Removal of subsidies does not imply removal of economic policies

Reducing or eliminating non-technical costs remains critical. International experience indicates that economic policies related to non-technical costs, such as regulatory expenses, marketing costs, land use fees, and financing costs, become more important as renewable energy reaches cost-competitive levels and participates in power markets. For example, in 2016 a PV generation project in the United Arab Emirates bid a price of USD 0.0242 per kWh in a power auction, and this price was only possible due to the country's land tax exemption policy, consumption tax exemption policy, long-term low-interest loans, and summer tariff policies.

The 12 measures proposed by the National Energy Administration in 2018 to reduce the regulatory cost burden on renewable energy companies should be sustained and strengthened in the post-subsidy era to reduce non-technical costs, especially unreasonable non-technical costs. On land policy, some regions still violate national regulations or collect unreasonable renewable energy resource fees and urban land use taxes. The basic principles of land availability and land cost for renewable energy development should be clarified and national policies should be fully implemented.

Consumption guarantees for renewable energy remain essential over the long-term

China issued its most recent policies guaranteeing the consumption of renewable energy power in May 2019. The policy establishes mandatory consumption targets and responsibilities, along with indicators in order to guide the consumption of renewable energy power. The policy includes aspects that promote both supply and demand of renewables, both in the near-term and long-term. After wind and PV prices fall below present grid tariffs for coal and subsidies are withdrawn, renewable uptake will be the most important factor affecting annual installations of wind and solar. To meet China's need to continue wind and solar installations and thereby achieve long-term national clean energy targets, renewable demand responsibility should at least remain stable or grow over time, to create space for sustainable growth of renewable energy.

Supportive policies are still needed for some renewable energy sources

Considering the renewable energy industry's development and diversity, it is important to continue the support of other kinds of renewable energy than wind and PV, such as biomass, CSP, geothermal, marine, as well as related technologies in battery storage, hydrogen, etc. For biomass power from agricultural and forestry residues, raw materials account for at least two-thirds of the generation cost. Prohibition of straw burning via education, agricultural transfer payments, and subsidies for procurement of biomass would support development of biomass power. For large-scale solar thermal plants, such as utility-scale concentrating solar, these remain in the initial stage of industrial development, but the energy storage and flexibility aspects of the technology suggest they will have value in the world's future renewable-based energy system. For CSP technologies, competitively-set tariffs for new projects combined with annual installation targets would ensure continued development. Either grid companies should be required to enter PPAs and the cost premium may be covered by the end-users through the retail electricity price, or a differential price should still be offered for these technologies through the renewable energy development fund. If such technologies participate in power markets, they could do so under a contract-for-difference arrangement.

Renewable energy participation in the power market

A dynamic power system is needed for cost efficient VRE integration

China's electricity market should be able to mobilize existing flexibility through efficient price signals and market services; and guide investments to bring flexibility sources through the market design.

The power system should be structured to efficiently dispatch so fluctuations and uncertainties can be handled without interfering with system security. This requires integrated market operation, deep participation in spot, balancing and ancillary service markets; and a process to connect, provincial, regional and national resources seamlessly.

A clear market design target model is needed, which will enable operating the power system of the future.

Figure 17: Timeline of regional spot power market establishment

Market design should gradually have renewable energy participate in the market

Renewable energy's participation in the power market will be a gradual process according to the direction of China's power system reform, as has also been the international experience. In the early stage, renewable energy power can participate in the power markets by bidding a production curve without quoting a price and take priority in market clearing as a price taker, to enable priority for renewable consumption. When the spot market is mature and stable, newly added renewable energy projects will likely participate in the power markets by bidding both quantity and price.

Renewable energy market participation should take many forms

For new projects, participation in the power market can be diversified by referring to international experience and domestic demand, including power purchase agreements signed with power consumers or trading companies, medium- and long-term contracts, competitive bidding by the government or trading companies, direct participation in the spot market, and combination of the aforesaid models.

For existing projects that previously had feed-in tariffs set as benchmark tariffs, set via competitive bidding, or tariffs including a subsidy, as well as benefitting from the full purchase guarantee policy, China should encourage their participation in the power market. Before a switch is made from the feed-in tariff model to the market premium model or the contract for difference (CFD) model, preconditions should be established. This includes that that the spot market should be a well-functioning market creating a robust reference price for such contracts to settle against.

Renewable energy should not partake in imperfect power market competition

Before the market is well-functioning, and effective competition is achieved, it is unhelpful for wind and PV to participate. It is recommended to continue the benchmark tariff parity pricing or auction-based pricing policies for wind and PV for a period. In 2019, China implemented a new auction system for PV generation. The major elements of this system, such as competitive allocation, national ranking, amended tariff, and forewarning management, are also applicable after the complete removal of subsidy for wind and PV. The feed-in tariff will be lower than the price of coal power through auction or bidding (in August 2019, the final bid prices for PV in projects auctioned were lower than the respective local coal benchmark prices).

Clean heating with a central role for district heating

With a supply of around 2,300 TWh, district heating is responsible for around 50% of the all heating demand in 2020. Heating sector reforms in China deserves attention due to large energy consumption, low cost options for decarbonization including reducing pollution and high potential for providing flexibility regarding renewable electricity integration.

Renewable heating development and planning needs priority

Renewable heating should have priority over other sources in urban heating networks for connection and utilisation. Regional energy transformation demonstration projects should include renewable heating targets, incorporate renewable heating into unified regional planning, and include renewable heating as an indicator in the regional ecological civilization construction evaluation system. Solar energy, biomass and geothermal energy technologies should be included in the preferred technology catalogue for air pollution, energy conservation and emission reduction.

Overall RE heating development goals should be put forward for the country and for key provinces. In the planning and construction process of new urban district construction, reconstruction of old city and construction of industrial parks (areas), China should combine the regional energy planning with urban development planning and prioritize the simultaneous development of renewable power and heating.

Promote the market competitiveness of renewable heating

Restrictions should be lifted on access to heating systems and encourage private enterprises to enter the clean heating sector. Market-oriented approaches such as competitive bidding should be incorporated in the sector. For users not covered by district heating, China should promote the development of decentralized renewable heating through the combination of user investment and government subsidies.

Support technology development and demonstration

Research and design optimization of new systems should be supported, including a multi-energy complementary system for renewable energy—which involves the integration of renewable energy and conventional energy systems, and can include combining renewable heating with other energy sources and storage.

Combined with the reformation of the power system and the construction of the power market, China should establish an information platform to coordinate energy flow and other data from the electric power grid and the heat networks.

Strengthen environmental supervision of renewable heating projects

For projects that may affect surface water, underground water, soil, or air quality, China should improve the overall supervision system before, during, and after the renewable heating project's initiation. This entails monitoring geothermal energy development and utilization, including real-time monitoring and dynamic evaluation of the exploration, development, utilization and environment condition of geothermal energy resources. Regulators should fully implement requirements for reinjection of geothermal tail water and ensure the balance of extraction and injection. Technical standards should be developed for biomass heating and NOx emissions from large biomass boilers shall be reduced. China should promote the manufacturing of standardized, serialized and complete set of equipment, and formulate standards for biomass heating engineering design, briquette-fuel products, moulding equipment, biomass boilers and emissions.

Improve the standard system for renewable heating

The testing and certification system for the renewable heating products should be strengthened, third-party testing and certification institutions should be established, and quality certification system for renewable heating equipment and engineering services should be developed and improved.

Renewable energy gas

Renewable gases can displace fossil gas while reducing methane emissions

Development of this industry requires coordinated management across departments and fields, especially the sorting and integration of upstream raw materials and promotion of consumption of renewable energy gas.

A collaborative management system for the biogas industry must be established

The responsibilities of the leading authorities and departments for the biogas industry shall be clarified and coordinated across the multiple departments of finance, development and reform commissions, agriculture, environmental protection, energy, housing and construction, taxation and quality inspection. Industrial goals, plans, policies, and standards shall be formulated jointly.

Supervision and management shall be strengthened

Professional third-party evaluation agencies should assess projects upon completion according to project feasibility report, implementation plan and operational impact of the project. A project grading evaluation mechanism considering environmental impact, technical advancement, sustainable operating capacity, and innovation shall be established, and grading linked with subsidy and tax policies to ensure the construction quality and actual production impact of the projects. The blacklist or credit system should also apply to such projects, to notify and penalize companies with records of multiple ineffective projects.

Private capital should participate in establishing collection, storage and transportation systems for agricultural organic wastes

Policymakers can establish investment subsidies, co-equity investments, long-term off-take contracts, and public-private partnerships. New ways should be explored to integrate private investment together with government investment in waste regulation, prohibitions on straw burning, fees for sewage and waste disposal, and environment taxes for livestock and poultry farms.

Preferential tax policy should be improved and include agricultural organic waste collection and treatment services in the scope of VAT refund and marginal relief.

Gas network companies should fully purchase biogas in accordance with the RE Law

The supportive policy for the construction of gas supply networks in rural areas shall be improved, and it shall be ensured that biogas and marsh gas power generation and central gas supply are treated equally in the market.

Biofuels

Bioethanol production should match reasonable rates of consumption

The official plans state that China should promote biofuel ethanol nationwide by 2020[22]. To ensure a stable supply of biofuel ethanol raw materials, policymakers should set production and consumption policies in accordance to avoid situations where biofuel ethanol producers cannot meet demand.

Increase research and development of biofuel ethanol from non-grain raw materials

Due to limits on raw material availability, should focus be on the research and development of biofuel ethanol from non-grain raw materials, realize nationwide use of biofuel ethanol.

Raw material management and regulation of the biodiesel upstream industry system should be strengthened. It is urgent for China to standardize the collection, transhipment, disposal and supervision of the upstream raw materials of biodiesel such as gutter oil. A long-term management mechanism should be established, and the regulation of the industry management system should be enforced through local legislation, to ensure the safe flow of raw materials such as gutter oil and provide a raw material guarantee for biodiesel production.

Part1:
Energy Transition Status

1 Global energy transition

Global energy transition shows uneven progress. The world is at the early phases of a long-term transition towards cleaner energy sources and more efficient consumption—changes which are critical to avoiding the worst impacts of climate change and reducing the other negative consequences of fossil fuel production and consumption. This chapter reviews the latest global energy sector trends and most recent developments. Overall, 2018 was a year in which renewable energy continued to grow strongly, but so did fossil fuel use and emissions. While several developments this year have been positive for the global energy transition, according to the analysis of several major international institutions the world is far from fully on the path to energy sustainability.

1.1 Fossil fuels

Coal

Coal consumption growth stagnated and several countries have begun to suppress coal use. World coal consumption slowed in 2018, growing 0.7%, similar to the prior year. Most 2018 coal consumption growth took place in Asia, particularly in China, India, and Southeast Asian countries; together, Asia accounts for almost three-fourths of world coal use.[23] Coal's share of power generation remained steady at 38%, and coal contributed 44% of global energy-related carbon emissions.[24] Coal still is the main source of heating and industrial fuel combustion in large parts of the world.

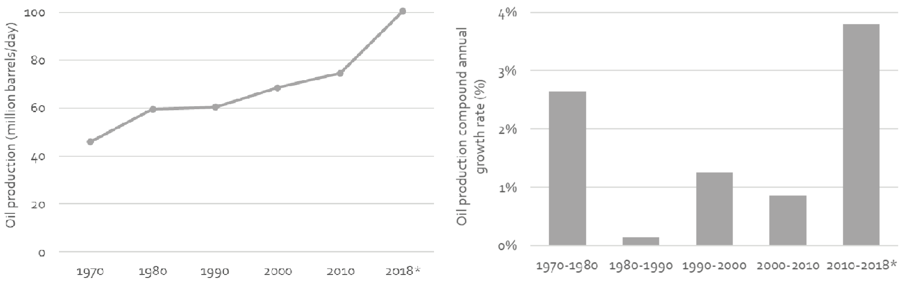
Perhaps more than any other energy source, trends in coal use have diverged, and many regions are moving away from the fuel. U.K. experiences long intervals with no coal in its energy mix at all.[25] Germany announced plans to gradually phase out its remaining coal plants over two decades, with most closures to take place in the 2020s. The U.S. is retiring coal plants at a rapid rate, and coal consumption has fallen 44% since its peak in 2007.[26] In both the U.S. and Australia, where the central government supports coal and adopts measures to keep coal plants open beyond their economic life, coal plants are still shutting due to their poor competitiveness with natural gas and renewable energy. This trend is now spreading to the developing world. Recently, India has seen a large number of coal plant cancellations, private companies and banks won't finance new coal plants, and an estimated 40 GW of existing coal is already considered stranded due to high operating cost.[27] Nearby Pakistan has also shelved planned coal plants for economic reasons.[28]

Oil

Oil consumption continues to rise and the oil market sees higher risk. Global oil consumption grew 1.5% in 2018, and surpassed 100 million barrels of oil per day, more than double the rate of consumption in 1970, prior to the 1970s energy crisis.[29] Oil price volatility, which experienced a lull during the past decade, has picked up recently, implying that countries with greater economic exposure to oil prices face greater uncertainty and investment risk. Increasingly, developing world countries such as China have the greatest such exposure: China is now the largest oil importing country.

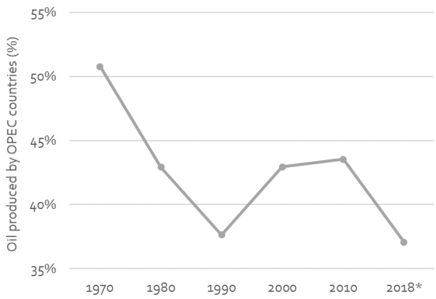
Global oil majors planning huge investments in oil infrastructure, with strong potential to be stranded if other technologies begin to compete with oil on the demand side. The IEA has estimated that US$ 1.3 trillion in oil and gas investment could be stranded by 2050, while the five largest international oil companies are estimated to plan US$ 550 billion on investments in oil and gas that are incompatible with targets of the Paris climate agreement.[30]

Figure 1-1: 1970-2018 Global oil production (left); 1970-2018 oil production compound annual growth rate (right)



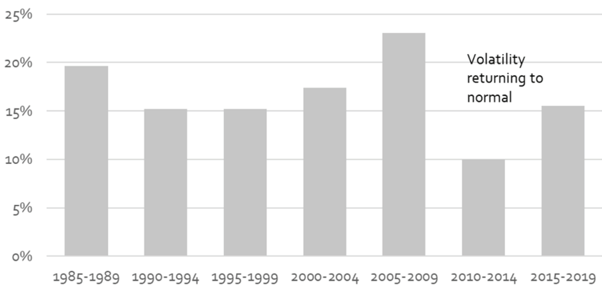
*Note: * is estimated value. Source: Energy Information Administration (EIA), accessed in April 2019*

Figure 1-2: 1970-2018 Oil production by OPEC countries



Note: Does not account for OPEC member country changes. Source: EIA, accessed in April 2019

Figure 1-3: World oil price volatility since 1970



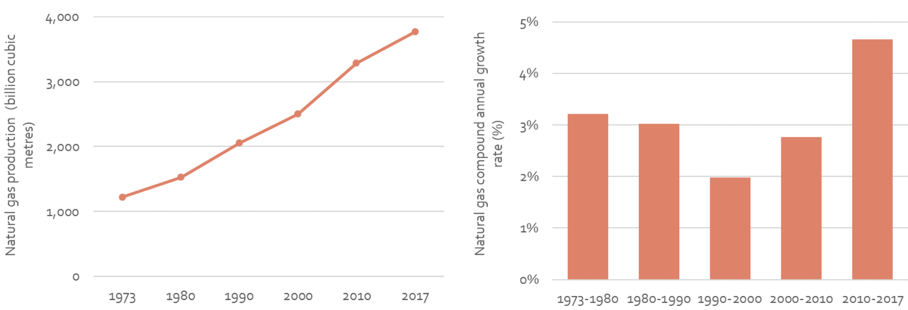
Note: Standard deviation of daily oil price futures expressed as percentage of average daily price for oil futures at Cushing, Oklahoma; source: EIA, accessed May 2019

Natural gas

Natural gas sees good trend worldwide, it is becoming an important energy source. Natural gas production and consumption also continue to grow strongly, rising 4.3% worldwide, higher than the 3% growth observed in 2017.[31] Gas demand has shown compound annual growth of almost 5%, driven in part by fuel switching from coal power to lower-cost and cleaner gas-fired power. Global gas consumption is now over triple the level of the early 1970s, and demand growth has been increasing. The United States accounts for over 45% of new natural gas production—much of it from associated gas connected to shale production—whereas gas demand in China has shown consistently strong growth in recent years.[32]

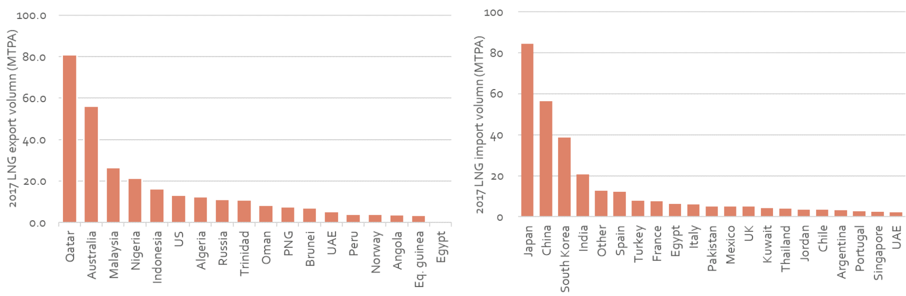
As a result of growing gas demand in Europe and Asia, international trade in liquefied natural gas has grown in importance in world energy markets. LNG trade depends on a limited number of exporting countries, and also offers limited flexibility, given the long lead-times required for constructing LNG infrastructure. If demand for LNG slows, or declines—such as due to competition from low-priced alternatives such as renewable energy and energy storage, and the mandate to reduce carbon emissions—such infrastructure faces risk of asset stranding. This poses severe economic risks for countries in the developing world that have financed such infrastructure.

Figure 1-4: 1973-2017 world natural gas production (left); 1973-2017 natural gas production compound annual growth rate (right)



Source: International Energy Agency (IEA), accessed in April 2019

Figure 1-5: 2017 LNG export volume by country (left); 2017 LNG import volume by country (right)



Source: (left) EIA, accessed in April 2019; International Gas Union, June 2018; (right) International Gas Union, June 2018

1.2 Renewable electricity

Driven by supporting policies and economic trends, renewable continued to grow rapidly. World installed hydro capacity reached 1,292 GW, an increase of 21 GW or 1.6% from the prior year.[33] Wind added 51 GW in 2018, reaching cumulative capacity of 591 GW, an increase of 9.5%.[34] Solar PV added 104 GW, reaching cumulative capacity of 486 GW at year-end 2018, an increase of 24.2%. Rounding out the renewable sources, according to International Renewable Energy Agency (IRENA) figures, there exist around 115 GW of biomass power of various kinds, 13 GW of geothermal, and 500 MW of ocean energy.[35]

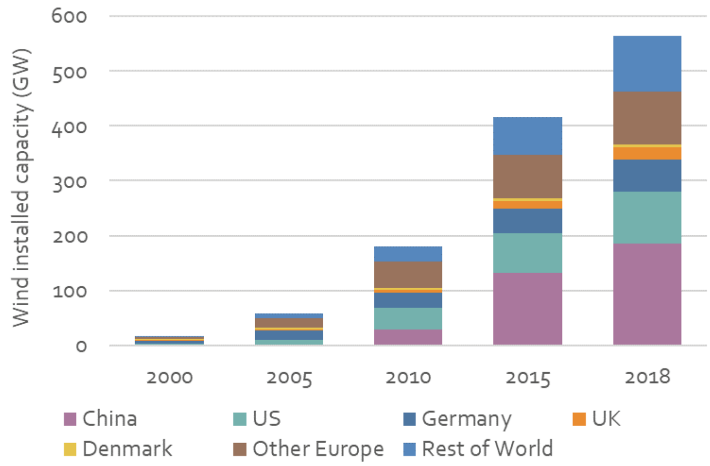
Renewable energy in 2018 accounted for a combined 26% of world electricity production, of which wind and solar accounted for 7% and hydro and other renewable sources 19%.[36] The growth of solar and wind is particularly impressive viewed on a longer time scale: World solar capacity has risen by a factor of 20x since 2009, and wind capacity has risen by a factor of almost 4x, despite a slowdown in new wind and solar additions in Europe. [37]

Over the past decade, wind and solar have become economically competitive with fossil fuels in the electricity sector, and in many countries these energy sources are now cheaper than continuing to operate fossil fuel power plants—even without considering externalities such as environmental costs. In the past decade, solar PV costs have fallen by around 80%, and wind by 30-40%.[38] These cost declines show no sign of slowing: solar PV costs fell a further 12% in 2018.[39] Battery energy storage costs fell 35% in just a single year, making renewable energy paired with storage competitive with natural gas and coal in many regions.[40]

Assuming this trend continues, and assuming the rapid price declines of energy storage continue to meet or exceed those previously experienced by wind and solar, renewable energy could experience even more rapid expansion in the decade to come. This is critical if the world is to limit emissions from fossil fuels. Furthermore, renewable energy must not only continue to grow, but begin to supply low-cost electricity for industry and transportation, which presently rely heavily on direct combustion of fossil fuels.

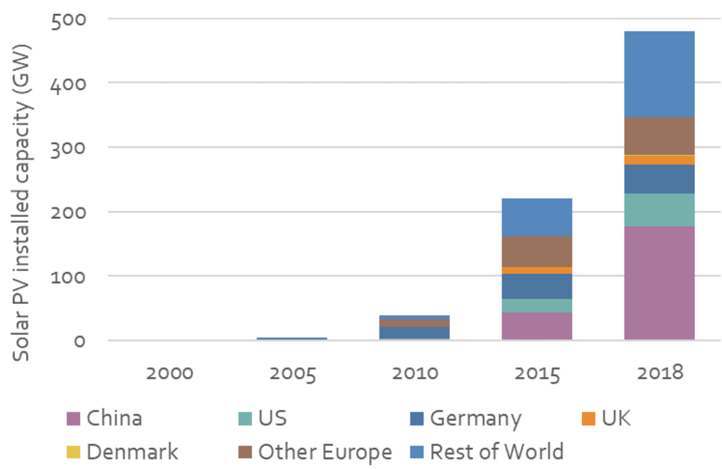
In recent years, growth in wind and solar has concentrated in a few countries with supportive policies—and growth has often depended on continuation of such policies. Recently, China has dominated wind and solar installations for this reason: China accounted for over 40% of new solar PV installations in 2018 and just under 40% of new wind installations. Over the next few years, as countries such as India, Brazil, and Australia ramp up wind and solar to take advantage of abundant resources and falling investment costs, renewable energy markets will face lower political risk and higher market risk. Already, renewable energy has diversified away from Europe and North America, and this diversification trend will increase.

Figure 1-6: Global wind installed capacity



Source: 2000-2015 data from International Renewable Energy Agency (IRENA), accessed in April 2019; 2018 data from IRENA, March 2019

Figure 1-7: Global solar PV installed capacity



Source: 2000-2015 data from IRENA, accessed in April 2019; 2018 data from IRENA, March 2019

1.3 Energy system development and policy

Global energy transition depends not only on shifting to new sources, but also on organization of national, regional and global energy systems. For renewable energy, variable energy sources such as wind and solar depend critically on the rules and organization of markets for electric power. In turn, the decarbonization of the world economy depends on both improved end-use energy efficiency as well as shifting sectors such as transport and industry to renewable energy, particularly from electricity. Technology, including improvements to existing renewable and storage technology, as well as new innovation in transport and materials, will also play a role.

Electrification is one of the central trends currently underway. According to IEA figures, 20% of final energy demand was provided by electricity as of 2018, but this may rise by 50% or more by 2050. Though many countries, especially in Europe and North America, are currently seeing stable or falling electricity demand, IEA projects power demand needs to go up by 90% by 2040, as transportation and industry continue to electrify. This estimate assumes 50% of passenger cars are electric by that time, and that freight, shipping and aviation do not electrify.[41] Recently announced electric freight truck models, and adoption of electric airplanes and ferries for some routes, suggest that technology in this field is developing rapidly.[42]

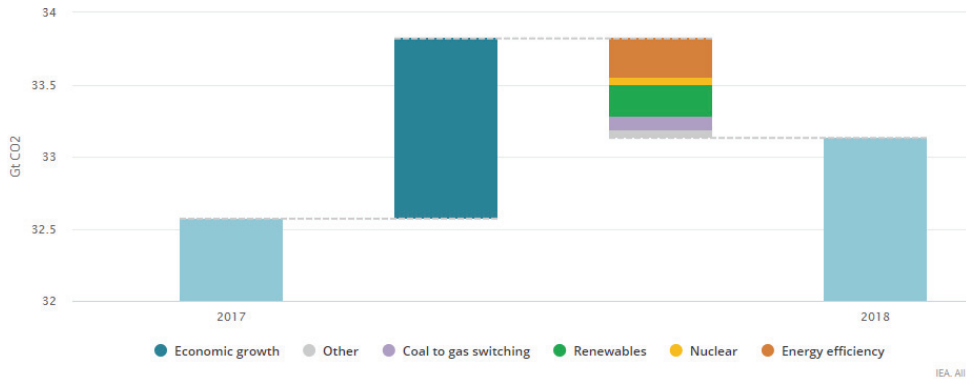
For electrification to contribute to addressing climate change, renewable energy must also scale up quickly, which requires investment, continued technology progress, and market reforms. IRENA projects that the world energy system will need US$ 110 trillion in investment through 2050, but the declining cost of renewable energy means that these estimates are not only falling over time, it represents a savings to the economy versus what would be required if the system remained dependent upon fossil fuels. IRENA estimates that reducing fossil fuel subsidies alone would save US$ 10 trillion over this period.[43]

While IRENA's projection requires a rapid and front-loaded transition to cleaner energy, the growth in renewable energy and energy efficiency required represents a growth factor lower than what wind and solar achieved in the past decade: IRENA projects that by 2030 the world would add around 300 GW of solar per year and 200 GW of wind per year, have over 157 million electric vehicles on the road, and over 155 million heat pumps installed. On the consumption side, energy efficiency would need to improve by 3.3% annually, instead of around 2% at present.

1.4 Climate action

Limiting global warming and related gas emissions still has a long way to go. In 2018 emissions related to global warming continued to rise, putting the world at increased risk of failing to meet targets to limit global climate change. According to the IEA's Global Emissions and CO_2 Status Report, in 2018 CO_2 emissions rose 1.7%, a new record, while the average atmospheric concentration of CO_2 reached 407.4 parts per million, compared to pre-industrial levels of 180-200. Coal power accounted for about 30% of annual emissions. While economic growth and increased energy consumption accounted for the emissions growth, energy efficiency and renewable energy production substantially mitigated what would have otherwise been a far larger increase.[44]

Figure 1-8: Change in global energy-related CO_2 emissions, 2017-2018, in gigatons of CO_2



Source: IEA, March 2019

As the Intergovernmental Panel on Climate Change (IPCC) noted in a special report in October 2018, the world is already experiencing the damaging effects of climate change due to human activity, and limiting warming would benefit both human and natural ecosystems, with immense benefits to the most vulnerable people and countries around the world. The report showed that limiting warming to below 2 degrees C worldwide would require around a 25% cut in net global emissions by 2030, and net zero global emissions by around 2070, while limiting warming to below 1.5 degrees C would require even faster action.

The IPCC stated that limiting warming to below 1.5 degrees C would require "rapid and far-reaching transitions in energy, land, urban and infrastructure (including transport and buildings), and industrial systems (high confidence). These systems transitions are unprecedented in terms of scale, but not necessarily in terms of speed, and imply deep emissions reductions in all sectors, a wide portfolio of mitigation options and a significant upscaling of investments in those options."[45]

Overall, the IPCC and UN Environmental Program assessed the world as not on track to meeting the objectives of the Paris climate accord, noting that there is still no sign of a peak in world emissions contributing to global warming. While the UNEP noted that some countries appear on track to meeting nationally determined contributions (NDCs), several countries are far off course, including the United States, Australia, and the U.K.[46]

1.5 World energy transition

The global energy transition responds to both global trends as well as policies undertaken at the national level. This sub-chapter represents an international collaboration of several countries that have historically led on policies aimed at energy transition. Developments and challenges faced by these countries illustrate and often prefigure similar changes and developments elsewhere.

China

China is in the beginning of an energy transition, and aims to cut coal use while encouraging renewables and introducing related measures. This emphasizes shifting economic development from high growth to high-quality growth, as it develops a clean, low carbon, safe, and efficient energy system. Though China raw coal production increased by 4.5% in 2018, its share in total primary energy consumption declined below 60% for the first time. China's oil and natural gas use and import dependence continue to rise, however.[47] China's wind and solar PV capacity continue to grow, and the country added 21 GW of wind and 44 GW of PV in 2018, while curtailment of wind and solar energy declined.[48] In the past year, China has begun to introduce a renewable energy obligation, renewable tendering policies, and subsidy-free wind and solar pilots. Chinese policy-makers have faced delays in building out the national Emissions Trading System (ETS) and regional spot power markets.

Europe

The European Union is in the midst of wide-ranging changes to energy and economic policies, which comes with new measures and goals. This is linked with long-term efforts to decarbonise the economy, reduce dependence on energy imports, and develop new energy technology sectors. Arguably the most far-reaching policy is the Clean Energy for all Europeans legislative package, also called the Winter Package, of eight legislative acts aimed at reaching the EU energy targets for 2030 and 2050. In general, the EU is introducing new governance frameworks, adding new regulatory policies, and reforming specific laws and policies. In the field of targets, the EU has introduced new reporting system, obliging member states every ten years to set out national objectives, targets and contributions for the five dimensions of the Energy Union.[49] The EU has also adopted a 32% binding target for the share of RES in final EU energy consumption by 2030. The EU has reformed and reinforced the Agency for the Cooperation of Energy Regulators (ACER), creating a more powerful agency to oversee the integrated energy market and decide on cross-border regulatory issues. The EU has also adopted several measures to empower consumers and prosumers to actively take part in the electricity markets.

Germany

Germany's energy transition continues, with increases in related targets and laws. The transition sees a trend of gradually increasing renewable electricity share and closures of coal and nuclear plants, while at the policy level the government is working on issues related to coal transition and electromobility. In the electricity sector, Germany reached a new high of renewable share: 38.2% of the power consumed was generated by wind, solar PV, biomass and hydropower.[50] Higher prices for carbon allowances in the EU ETS, along with lower gas prices, encouraged fuel switching from coal to gas. Nuclear output remained stable, leading up to the next nuclear plant retirement this year. Looking forward, Germany's governing coalition agreed to coalition treaty agreed to increase the target for the expansion of renewables in power consumption to 65% by 2030.[51] The government has also prioritized grid expansion, introducing a new law that allows accelerated approvals for power lines. In January 2019, Germany's coal commission concluded work with a proposal for phasing out coal by 2038, building strong and sustainable regions, modernizing the power and energy system as well as absorbing negative effects on vulnerable affected groups.

Denmark

Denmark continues to add renewable capacity, and has developed clear long-term energy transformation goals. Renewables contributed a third of final energy consumption in Denmark in 2017, and in terms of power generation the country sets a new world record of covering 44% of Danish power demand by wind. Solar now contributes 2.3% of total power production.[52] Denmark is recognized worldwide as a pioneer in offshore wind as well as for its redesign of the power and heating sectors to accommodate a high share of variable wind generation.

Denmark will easily surpass its EU obligations of 30% of final energy consumption from clean energy by 2020. This year, political negotiations on a new Danish energy agreement resulted in new targets for the period beyond 2020: Denmark will target 55% of gross final energy consumption by renewable energy sources by 2030, a further expansion of offshore wind, increased electrification of the Danish energy sector, and an explicit target to eliminate coal in the power sector by 2030.[53]

United States

The energy transition in the U.S. is complex due to the implementation of the federal system. Given the different priorities and policy responsibility division between the federal and state governments and relatively strong role of market forces in driving the fuel mix there are big regional differences in energy transitions in the U.S.. The Trump administration aims to propel the U.S. to lead the world in both oil and natural gas production, taking advantage of a long-standing trend towards greater domestic production of these fuels.[54] The Trump administration has also modified or reconsidered Obama-era energy-related policies such as the U.S. commitment to the Paris Climate Change agreement, the Clean Power Plan, and vehicle fuel efficiency standards. The Trump administration has also sought to keep coal plants open.[55] Nevertheless, many federal policies promoting renewable energy technology remain in place. State governments—such as California and Colorado—are increasingly adopting targets to transition electricity or energy systems away from fossil fuels.[56] In many U.S. regions, wind and solar are now cheaper than the operating costs of existing conventional power plants.[57] Electric vehicle adoption is growing, and the development of battery technology has led to an increasing focus on hybrid power plants that include energy storage, especially in areas like Hawaii and California that already feature high renewable energy shares.[58]

1.6 COP24 and CEM9

World leaders and countries continue to make gradual strides toward implementing the Paris climate accords through global agreements and technical cooperation activities. In this section, we highlight developments over the last year at the Poland climate change conference and the Council of Energy Ministers in Denmark.

COP24

Carbon-cutting agreements were made, but still lacked clear implementation method. The 2018 United Nations Climate Change Conference was held in Katowice, Poland (COP 24) in December 2018. The major achievement agreed upon by countries on COP 24 Katowice was putting the 2015 Paris Agreement into concrete practices. To maintain the pre-determined standard of limiting temperature rise to below 1.5C, countries on COP 24 agreed on how government will measure, report on and verify their emission-cutting plans. [59] Fifty countries signed the *Solidarity and Just Transition Silesia Declaration*, which required governments to create employment opportunities and infrastructures to incentive transition to low-carbon economy. [60] However, countries have yet to agree on the methods to implement such plans.

CEM9

Power system flexibility campion established during CEM9. The Clean Energy Ministerial (CEM) is a global forum that fosters a transition to clean energy technology through programs and campaigns. CEM 9 took place in Denmark and Sweden in May 2018, its theme focusing on innovation and competition in moving towards a low-carbon world. Members launched four new campaigns, including the Power System Flexibility Campaign, which would be carried out in partnership amongst industry and governments.[61] The IEA's *Status of Power System Transformation Report* was launched at CEM 9. The report suggested several ways to improve flexibility of the power system. It emphasized that capital investment is not the prerequisite to operate a more flexible power plant and that changes in operational practices in existing plants could also be cost-effective. Secondarily, flexibility could also be improved by retrofit options or power plant technologies. Thirdly, discrepancies emerge as the power plant system requires cost-efficient operations and individual power plants require maintaining profitability. Thus, options including policy, market and regulatory instruments could be useful to coordinate individual power plants and the whole power system in light of this issue.[62]

1.7 Conclusion

International energy and carbon trends continue to evolve in ways that are both constructive towards achieving global climate goals—such as in the case of renewable energy growth and declining costs—while remaining inadequate to achieving these goals. Indeed, it is a paradox that much of the world is beginning to adopt policies to advance clean energy deployment and shift away from coal, but at the same time fossil fuel use and carbon emissions continue to rise. To prevent the worst effects of global climate change, the entire world must accelerate energy transition efforts.

As the world's largest energy consumer, China plays a central role in many aspects of the global energy transition underway. The next section analyses trends in China's energy transition in greater detail, showing that in many respects, China mirrors the trends described above.

2 China energy transition status

China is in the beginning of an energy transition with the aim of building an energy system for the future. At the 19th National Congress of the Communist Party of China, President Xi Jinping confirmed that China will promote a revolution in energy production and consumption. The country's plans emphasize shifting economic development from high growth to high-quality growth, a paradigm shift that also applies to the energy sector. With the important milestones for 2020, 2035 and 2050, China plans to develop a "clean, low carbon, safe and efficient energy system."[63]

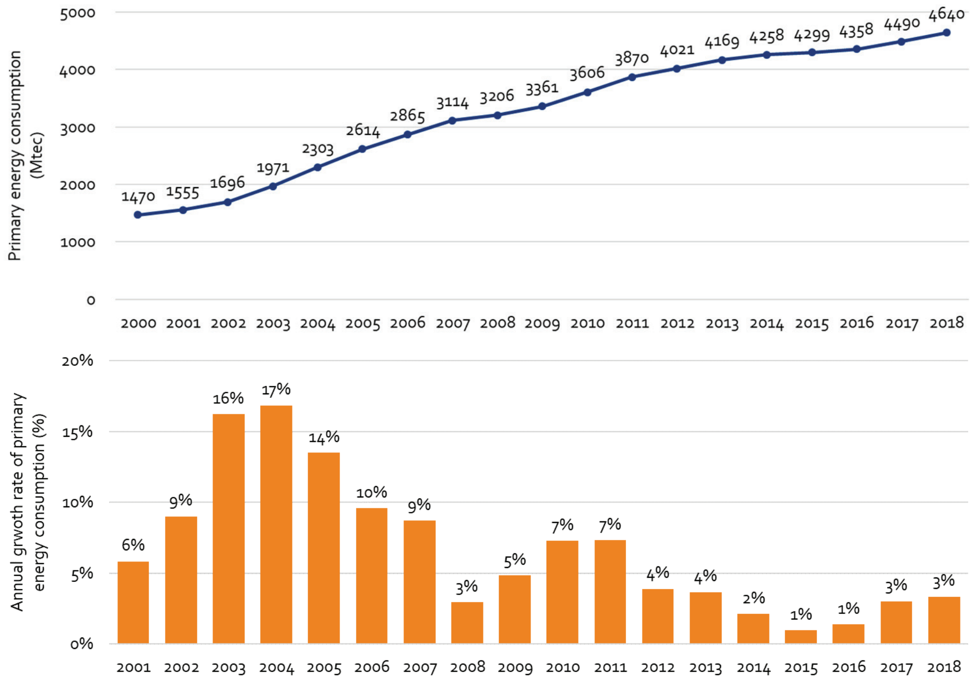
This chapter reviews statistics of China's energy sector in 2018, including the production and consumption of energy, coal, oil, gas and electricity. We then provide insights into China's strategy shift over the century in which China experienced three different phases in its focus of energy development. New natural gas receiving stations, a Feed-in Tariff for nuclear power plants, the establishment of a national Emission Trading System (ETS), and the New Blue Sky Action Plan all constituted milestones toward a cleaner energy transition in 2018.

2.1 Energy production and consumption

China's energy trend shows slowing growth and improving efficiency. Despite slower economic growth, China's primary energy consumption continues to reach new heights. The country's energy sector is also on track to achieve carbon-reduction goals faster than previously envisaged. In 2018, China's GDP grew by 6.6%, a decrease of 0.2 percentage points from 2017, the lowest level since 1990. Primary energy production reached 3,770 Mtce (110 billion GJ), an increase of 5% year-on-year, in which the added value of the secondary industry was 40.7%.[64] In part due to the trade war with the US, investment, domestic consumption, and export capacity has slowed.

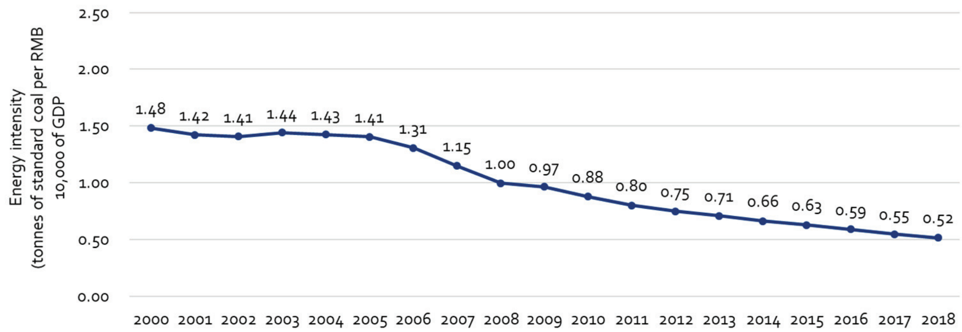
Primary energy consumption reached 4,640 Mtce (136 billion GJ, based on coal equivalent calculation) in 2018, an increase of 3% year-on-year. Non-fossil energy accounted for 14.3%, implying China's 2020 target of 15% non-fossil energy will likely be achieved ahead of schedule.[65] The China Electric Power Planning and Engineering Institute forecasts that China's energy consumption growth will slow in 2019 and reach 4,730 Mtce for the full year.[66] Gradual improvement in energy intensity of the economy continued: energy consumption per unit of GDP decreased 3.1% in 2018, indicating an increase in energy efficiency.[67] EPPEI also forecasts that China's energy intensity will continue to decline by more than 3.0% in 2019.[68] The energy-intensive steel manufacturing industry has completed the 13th Five-Year Plan target of reducing outdated production capacity of 150 million tonnes ahead of schedule in 2018. The industry will shift from a high-quantity development phase to a high-quality phase in 2019.[69]

Figure 2-1: 2000-2018 China final energy consumption (top); 2000-2018 annual growth rate (medium); 2000-2018 China's energy intensity (bottom)



Source: National Bureau of Statistics (NBS), accessed in April 2019

Figure 2-2: 2000-2018 China energy intensity



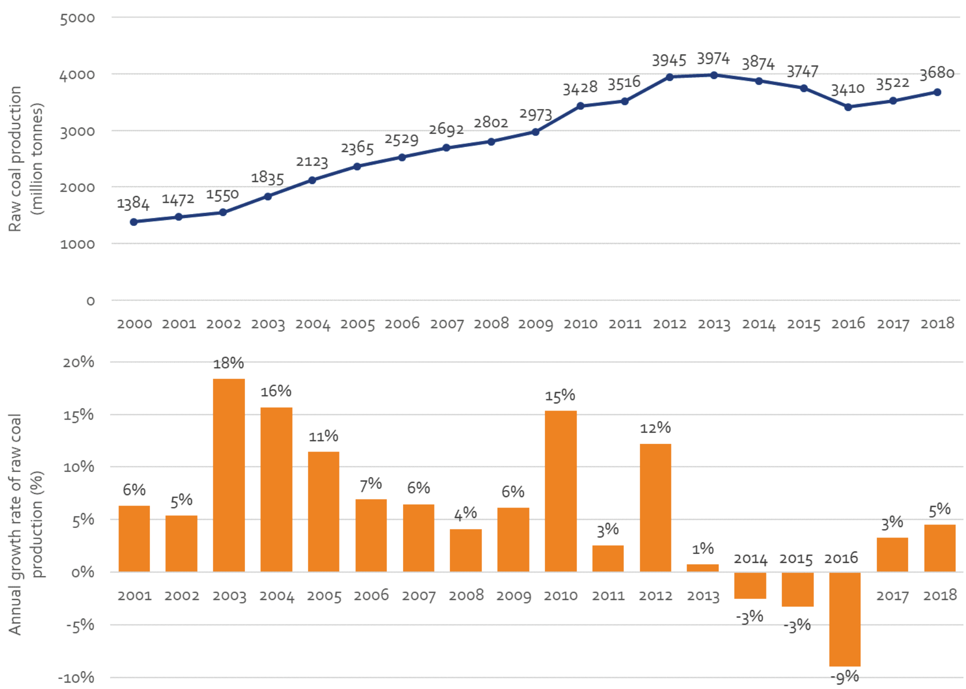
Source: NBS, accessed in July 2019

2.2 Coal

Coal production growth has slowed from earlier highs. To curb CO_2 emissions and transition to clean energy, China is working to decrease the share of coal in its overall energy mix and decrease the dominant role of coal in electricity generation. In 2018, China produced 3.68 billion tonnes of raw coal, with an annual growth rate of 4.5%. The government has further promoted supply-side energy structure reform through phasing out outdated coal production capacity and stabilizing coal prices. The coal industry has achieved 30 million tonnes of capacity reduction in 2018 and has cumulatively completed 86.3% of the 13th Five-Year Plan target.[70] To reduce fluctuations in coal prices, the coal market has increased the proportion of medium- and long-term trading contracts and the government has further reformed coal prices in an effort to stabilise supply and demand.[71]

Residential consumption of coal has decreased due to policies aimed at controlling emissions. Nevertheless, due to industrial consumption growth, in 2018 China's coal consumption reached 3.84 billion tonnes, an increase of 1% year-on-year.[72] This is the second consecutive year showing absolute growth. The proportion of coal used for power generation increased by 8% compared with that of 2017.[73] On the coal production side, mining will continue to shift toward the most cost-efficient billion-tonne coal bases, meaning coal mining capacity is likely to further increase in 2019. Coal consumption is expected to remain stable.[74]

Figure 2-3: 2000-2018 China raw coal production (top); 2000-2018 annual growth rate of raw coal production (bottom)



Source: 2000-2016 data from NBS, accessed in April 2019; 2007-2017 data from NBS, December 2018; 2018 data from NBS, February 2019

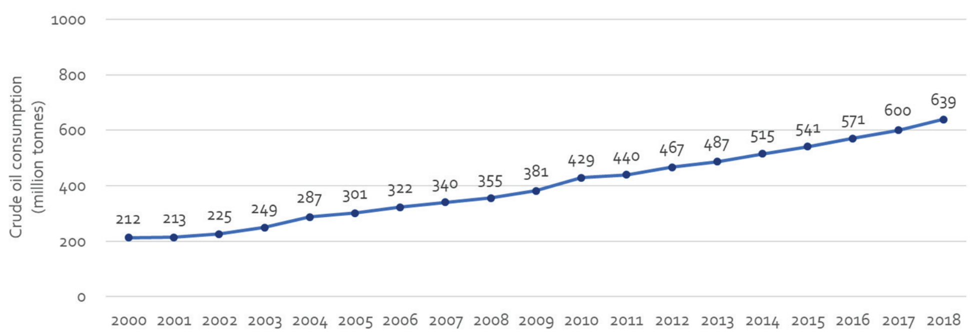
2.3 Oil

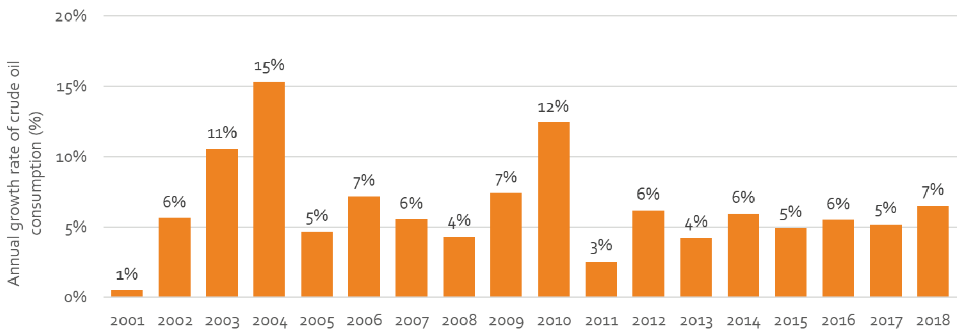
China's domestic oil production decline has slowed. The production and consumption of oil remains a severe challenge for China's energy transition, as the decades-long macro-trend of decreasing domestic production and rising import dependence continues. Despite efforts to boost flagging domestic production and reduce consumption growth, crude oil production in 2018 reached 189 million tonnes, down 1% compared to 2017, while the reduction rate rebounded 5 percentage points. In recent years, the quality of China's exploitable oil fields has dropped significantly, which results in increased production costs and reduced incentive for companies to develop new oilfields. Under the guidance of low-carbon policy, the government will increasingly prioritise clean energy to meet incremental energy demand, potentially dampening long-term demand for high-cost domestic crude oil.[75]

China's crude oil consumption increased by 6.5% in 2018, reaching 639 million tonnes, 3.4 times more than domestic output. Oil import dependence reached 72%, an increase of 2.4 percentage points from the prior year. Electrification in the transport sector dented oil demand: China sold 1.2 million plug-in electric vehicles nationwide in 2018, an increase of 140% over 2017. Electric buses in China displaced 0.26 million barrels per day of oil demand—a relatively large displacement compared to cars, resulting from high daily usage.[76]

In 2019, China will continue various efforts to reduce oil import dependency, including targeting domestic oil production to reach 190 million tonnes in 2019.[77] As EV sales continue to rise, they should increasingly begin to displace demand growth, though the turning point will require a few more years.[78] In the near-term, demand growth should continue, and import dependence will rise.

Figure 2-4: 2000-2018 China crude oil consumption (top); 2000-2018 annual growth rate of crude oil consumption (bottom)





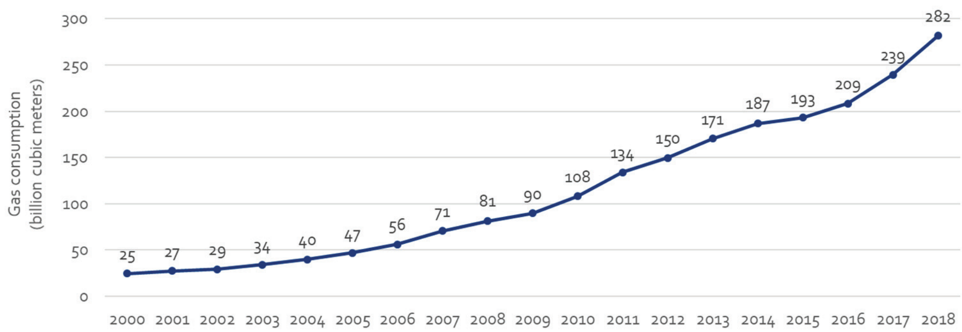
Source: 2000-2015 data from NBS, accessed in April 2019; 2016 data from NBS, February 2017; 2017 data from NBS, February 2018; 2018 data from NBS, February 2019

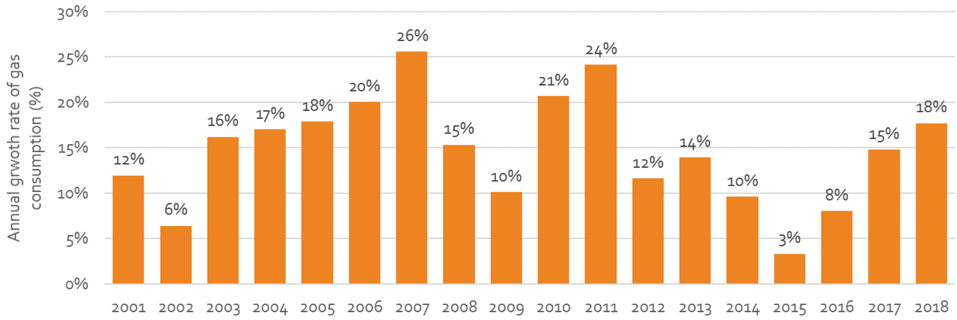
2.4 Natural gas

Natural gas consumption surged. Natural gas, which is relatively clean compared to coal, is the fastest-growing fossil energy in China. In 2018, China's total natural gas production reached 160 billion cubic metres (bcm), an increase of 8% year-on-year, among which the increase of shale gas production reached 22.2%.[79] To achieve the national target of natural gas accounting for 10% of primary energy consumption by 2020, the NEA has promoted fuel switching from coal to gas during the 13th Five-Year Plan period. Natural gas consumption increased by 18% in 2018, with a total volume of 282 bcm, 10 percentage points higher than the growth rate of natural gas production.[80]

Natural gas import dependence rose to 45.3%, an increase of 6.2% year-on-year.[81] Over the last decade China has signed a series of contracts with overseas suppliers of liquefied natural gas (LNG), and in 2018 LNG imports increased by 41.1%. Australia became the largest supplier, accounting for 42% of China's LNG imports. Thanks to a new import natural gas pipeline from Kazakhstan commissioned in 2017, pipeline gas imports increased by 20.6% year-on-year in 2018.[82] Natural gas import dependence is expected to increase in 2019 and the number of new LNG contracts will increase by 20%. Kazakhstan's pipeline oil and gas imports will double, reaching 10 bcm per year. [83]

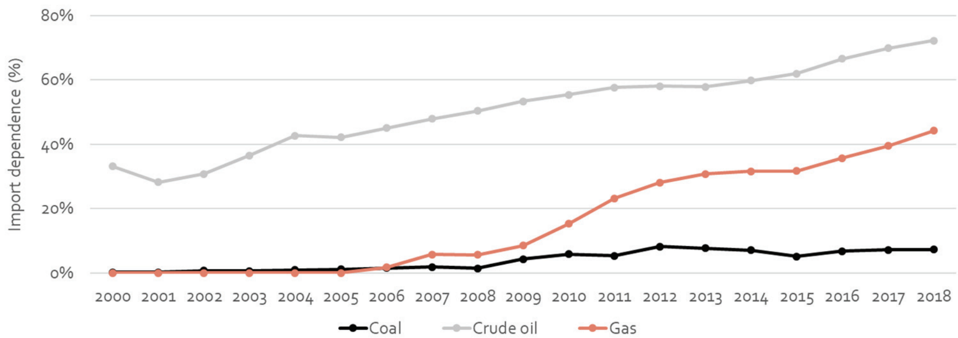
Figure 2-5: 2000-2018 China gas consumption (top); 2000-2018 annual growth rate of gas consumption (bottom)





Source: 2000-2014 data from NBS, accessed in April 2019; 2015 data from NBS, February 2016; 2016 data from NBS, February 2017; 2017 data from NBS, February 2018; 2018 data from NBS, February 2019

Figure 2-6: 2000-2018 China coal, oil and gas import dependence

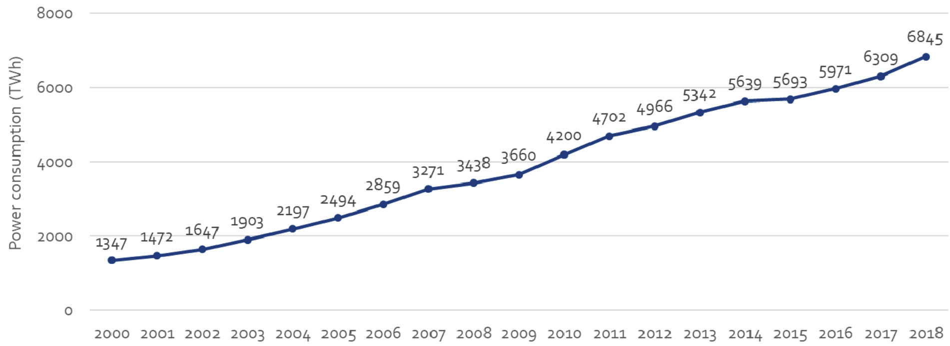


Source: NBS, accessed in April 2019

2.5 Electricity consumption

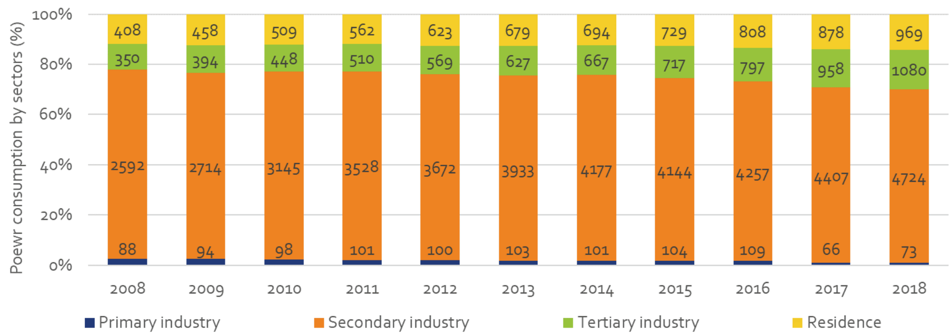
Electricity consumption continued to increase. China's total electricity consumption in 2018 reached 6,846 TWh, an 8.5% annual increase, the highest annual growth since 2012. Secondary industry contributed five percentage points of this growth, where high technology and equipment manufacturing industries are the growth points, whose electricity consumption grew 9.5%. Tertiary industry electricity consumption also increased sharply, led by growth in electricity consumption by the telecom, software, and information technology sectors. As the trends of urbanisation, electrification of heating, and rising living standards continue, residential electricity consumption also continued to show strong growth.[84] However, the growth rate of power consumption may decrease in 2019 due to economic normalisation and stricter air pollution control policies affecting energy-intensive industries.[85]

Figure 2-7: 2000-2018 China power consumption



Source: 2000-2007 data from NBS, accessed in April 2019; 2008-2018 data from China Electricity Council (CEC), accessed in April 2019

Figure 2-8: 2000-2018 China power consumption by sector



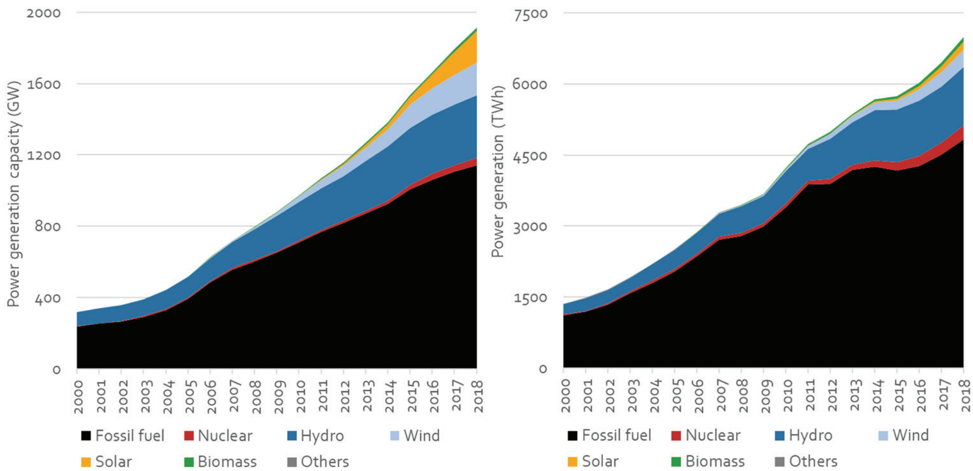
Note: Power consumption of agriculture, forestry, grazing and fishery moved from primary industry to tertiary industry since 2017. Source: 2000-2007 data from NBS, accessed in April 2019; 2008-2018 data from CEC, accessed in April 2019

2.6 Electricity generation mix

Non-fossil energy used for electric generation increased. In 2018, growth of coal power generation continued to decrease, while nature gas and non-fossil fuel filled in the gap. The generation efficiency of fossil and non-fossil both increased. China added 120 GW of new power generation capacity in 2018, reaching 1,900 GW in total. Coal capacity additions continued to slow, while natural gas power capacity grew faster. The electricity sector generated 6,990 TWh of electricity, 30.9% of which was from non-fossil energy sources, of which 26.7% was renewables and the remainder from nuclear.[86] Incremental non-fossil electricity generation increased by 11.1%.[87]

To accelerate the resolution of overcapacity in the coal power sector, the NEA and NDRC announced plans to phase out 11.9 GW of outdated coal power units in 2018.[88] Under the carbon emission control targets, the NEA and the Ministry of Ecology and Environment (MEE) jointly ordered energy saving retrofit for 100 GW-and-above coal power units in 2018. The government requires shutdown of any units that still do not meet standards after retrofit or upgrades.[89] In 2019, these trends of increasing non-fossil output and closure of outdated coal capacity are likely to continue.

Figure 2-9: 2000-2018 China power generation capacity (left); 2000-2018 China power generation (right)



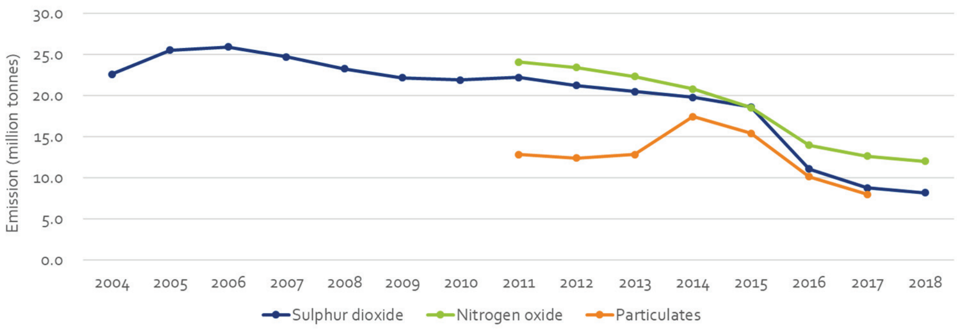
Source: NBS, accessed in April 2019; CEC, accessed in April 2019; China National Renewable Energy Centre (CNREC), March 2019[90]

2.7 Carbon and other air pollutant emissions

Carbon and major pollutant emissions intensity of production continued to decline. The Chinese government issued official data for the energy sector's carbon emissions in 1994 (2,795 Mt), 2005 (5,404 Mt) and 2012 (8,688 Mt).[91] As the largest domestic coal consuming sector and an important carbon emitter, China's coal power plants run more efficiently and with lower emissions per unit of production. China has eliminated coal units below 300 MW in capacity and tightened emissions standards for newly built units. In 2019, China will continue to carry out emission reduction retrofit projects in the coal power sector. Reduction of coal consumption outside the electric power sector will proceed in parallel, reflecting policies and economics favouring continuing electrification of industrial production and heating.[92]

The main pollutants such as SO_2, NO_x and particulates all show a declined trend due in part to stricter emissions enforcement in 2018. The Ministry of Ecological Environment (MEE) carried out spot checks of environmental monitoring data at heavy industrial pollutant discharge units and established an information sharing platform with market supervision departments.[93] These efforts resulted in lower emissions and contributed to improved air quality. In China's 338 cities at or above prefecture level, ambient PM10 concentrations dropped by 5.3% and ambient PM2.5 dropped by 9.3% in 2018 versus the prior year, and the nationwide average number of haze days declined from 27.6 days in 2017 to 20.5 days in 2018. Acid rain measurements showed improvement in the majority of Chinese regions, and their average frequency reached the lowest level since the record began in 1992.[94]

Figure 2-10: China's historical SO_2 and NO_x and particulates emissions



Source: NBS, accessed in June 2019

2.8 Energy system transition process from 2000 to 2018

Building a clean, low carbon, safe and efficient energy system. From 2000 to 2018, China's energy development has experienced three distinct phases: In the first phase, from 2000 to 2009, the main priority was ensuring the security of energy supply. In the second phase, from 2010 to 2015, policymakers looked to enforce reforms to the national energy structure and increase clean energy supply. In the third phase, from 2016 onward, policymakers aim to improve overall efficiency of energy sector and to speed up coal phase out process practically.

In Phase I, China's economy entered a stage of rapid development, securing energy supply was the major task of energy development. Coal had the lowest cost and became the most important source of energy. By 2009, coal accounted for 71.6% of primary energy consumption, and thermal power (mainly coal) accounted for 81.3% of power generation.[95]

In Phase II, the government proposed quantitative goals aimed at reducing carbon emissions and adjusting the energy structure, and incorporated the goals into economic and energy development plans. The goals stated that by 2030, carbon intensity of the economy (CO_2/GDP) should improve by 60-65% compared to that of 2005, and the proportion of non-fossil energy in primary energy consumption should increase to 20%.[96] The government established carbon market pilots and renewable energy subsidy mechanisms in form of feed-in tariffs. Non-fossil energy received policy support and renewable energy developed rapidly.

However, it was hard for coal power to phase out immediately as large number of units were installed in past decades. Coal power development helped with growth of added value in upstream and downstream industries and provided job opportunities locally.[97] Provincial governments preferred such power supply also because it was the cheapest, and without ancillary service markets established by that time, coal power units was necessary to back up intermittent renewable power sources.[98] Coal power units still enjoyed the incentive of certain amount of guaranteed purchase by grid companies. At the same time, due to slowing economic growth, coal production experienced negative growth for the first time in decades, and coal power overcapacity became an issue in several regions.[99] By 2015, the country no longer faced energy supply shortages, and the national energy structure was beginning to grow more diverse, more low-carbon, and increasingly market-oriented. Air pollution remains a major public concern.

In Phase III, the government deepened supply side structural reform and improved energy consumption to boost overall operation efficiency of the energy system. This included incorporating energy into the ecological framework emphasizing the phase-out of coal and development of clean energy on the supply side, as well as the clean and efficient use of the demand side. NDRC and NEA set a target of keeping total coal power capacity under 1,100 GW by year 2020.[100] During the 13th Five-Year Plan period, more than 20 GW of outdated thermal power capacity was targeted for closure, and any remaining coal-fired units under 300 MW should meet ultra-low emissions standards.[101] Outdated enterprises without development potential, as well as coal power units not in compliance to technical and emission regulations, shall be suspended.[102] The guaranteed purchase hours of coal power plants approved by 15 March 2015 should decrease by at least 20% annually.[103]

The government has also worked to expand the share of clean energy in the power and heating sectors. In the power sector, driven by the non-fossil targets and incentives made in Phase II, renewable energy has become the major power source for incremental power demand and is gradually replacing existing coal power in some regions.[104] The share of renewable power generation increased from 24.2% in 2015 to 26.7% in 2018.[105] In the heating sector, the government established clean heating pilots and an electricity substitution program.[106] With subsidies for fuel switching from coal to gas and coal to electricity projects, the consumption of natural gas increased rapidly, helping replace inefficient and highly-polluting burning of loose coal (*sanmei*) and fuel oil. By year 2018, the power replacement program has replaced 60 million tonnes of loose coal burning.

The economic structure of China has undergone shifts during Phase I to Phase III. The tertiary industry (namely, the service sector) has been gradually becoming a new leading economic growth point. In secondary industry, high-tech industries and equipment manufacturing industry that possess relatively low energy consumption and high added value also grew more rapidly than traditional industries.[107] On the consumption side, new business models and technologies such as distributed generation, electric vehicles, and multi-energy complementarity (enabling multiple energy sources to complement one another flexibly) are also expanding, eventually helping China transit into a low-emission energy society.

2.9 Major changes in 2018

Energy sector investment

Overall investment dropped while renewable energy is still attractive. In 2018, China remained the world's largest energy investment market, although its overall sector investment dropped by 1.5% compared to 2017.[108] The investment of newly added coal-fired power plants decreased by more than 60% and energy efficiency improved by 6% in the past three years, which led to the investment decrease. In contrast, about 70% out of

US$ 120 billion investment on power sector was spent on renewable energy.[109] According to EY's Renewable Energy Country Attractiveness Index, China was the most attractive renewable energy market in 2018, offshore wind and solar PV are the most attractive technologies.[110] However, China's renewable energy sector is undergoing a transition from subsidies even as the cost of wind and solar continues to decline. Slower investment, due to a change in supporting measures, will eventually give way to expanded application of wind and solar in newer applications and regions.

Natural gas infrastructure

Natural gas infrastructure build-out continues. Due to shortages of residential gas supplies in winter 2017, China promoted expansion of gas pipelines and LNG receiving stations in order to increase gas supply capacity.[111] The build-out of gas infrastructure included both pipelines and LNG import terminals. New pipeline corridors include routes from Central Asia to Xinjiang, Russia to Heilongjiang, Myanmar to Yunnan. The crossing project of the Sino-Russian East Line natural gas pipeline was completed in March 2019.[112] LNG terminals continued to grow, and as of February 2019, China has 51 LNG receiving terminals and 160 land-based small-scale LNG plants.[113] As one of the largest importers of LNG, China is also developing its own markets for LNG trading; the Chongqing Oil and Gas Exchange completed its first international LNG transaction in September 2018.[114]

Nuclear power feed-in tariffs

Tariff set for three recently completed nuclear power plants. NDRC announced the feed-in tariff policy for the first three Third Generation nuclear power plants, all of which went online in 2018. The tariffs range from RMB 0.4151/kWh to RMB 0.4350/kWh. The policy is in effect until the year end 2021.[115] The price range is lower than the levelised cost estimated by the China Nuclear Energy Association (RMB 0.5/kWh).[116]

Table 2-1: Feed-in tariff of the first three Third Generation nuclear power plants

Project Name	Feed-in tariff
Guangdong Taishan Nuclear Power Plant Phase I	RMB 0.4350/kWh
Zhejiang Sanmen Nuclear Power Plant Phase I	RMB 0.4203/kWh
Shandong Haiyang Nuclear Power Plant I	RMB 0.4151/kWh

Source: National Development and Reform Commission (NDRC), March 2019

Spot power markets

Eight spot power market pilots have launched. NDRC and NEA jointly announced the first batch of spot power market pilots in August 2017. These pilots covered eight regions and aimed to complete market designs by the end of 2018.[117] Almost all pilots have faced delays. For instance, the Zhejiang pilot saw disagreements among policymakers and grid officials concerning grid participation in market organization and annual account settlement.[118] Toward the end of 2018, the government required the eight spot market pilots to accelerate the research and preparation process.[119] All should start commissioning by the end of June 2019 provided no special obstacles arise, and provinces should report progress monthly to responsible government departments. On 15 May 2019 and 16 May 2019, Guangdong Power Exchange Center completed the transaction settlement in the Guangdong day-ahead and intra-day spot power market, a first for any of the country's eight spot market pilots.[120] A month later, Inner Mongolia started simulation of its spot power market on 26 June 2019. So far, the first eight spot power market pilots have all launched.[121]

Electric vehicles and battery energy storage

China's EV and grid-side energy storage market has continued to expand rapidly. In 2018, the sales of all passenger vehicles in China declined the first time since 1990, while new energy vehicles continued rapid sales growth.[122] China has ranked as the largest electric vehicle market in the world for four years running, and 2018 saw 62% of global electric vehicles sold in China.[123] Battery electric vehicles dominated the incremental electric vehicle market but the market for hybrid electric vehicles also showed strong growth.[124] The Corporate Average Fuel Consumption (CAFC) and New Energy Vehicle (NEV) dual-credit mechanism and the stage six emission standard of light-duty vehicles were the two major mechanisms issued in 2018 to facilitate the development of electric vehicles. The EV transition has benefited from falling battery costs, which have declined 40% from 2016 to 2018.[125] CNREC and the China Energy Storage Alliance (CESA) jointly expect that the cost per kilometre driving distance of electric vehicles should be competitive with fossil fuel vehicles of the same category by 2025.[126]

The grid-connected energy storage sector also showed strong growth in 2018. Newly-built battery energy storage facilities exceeded 600 MW, of which 36% was on the grid side.[127] Cumulative installed capacity reached 1,020 MW.[128] On the grid side, for the first time China has operational battery energy storage at the 100-MW scale. NEA issued a policy in 2019 to encourage energy storage participation in the ancillary service market.[129] CNREC expects that the market demand for grid side energy storage facilities will expand rapidly in 2019 and 2020.

Table 2-2: Sales of electric vehicles in 2017 and 2018

Types of electric vehicles	Sales in 2017	Sales in 2018	Growth rate
Battery electric vehicles	460,150	718,352	56.1%
Plug-in hybrid electric vehicles	97,475	233,440	139.5%
Total	557,625	951,792	70.7%

Source: China Passenger Car Association (CPCA), accessed at July 2019

National carbon market

China's national ETS marks first anniversary. China's national ETS was officially launched at the end of 2017. At the time, the schedule for establishing the ETS called for a preparation phase, followed by trial operation, and then official operation. The ETS currently remains in the preparation period. China has been making efforts on regulation system building, infrastructure construction, verification of historical emission data from major emissions entities, capacity building, and initiating carbon trading in the power generation industry. A national data reporting system has been established with industrial emissions data from 2016 and 2017. Although the design of the allocation system has yet to be published, an anonymous expert cited by Energy Observer stated that policymakers plan to tighten carbon allowance allocation principles and put into place an allowance distribution mechanism using baselines.[130]

Air quality improvement

New Blue-Sky Action Plan released. The State Council issued a new three-year air pollution control plan in 2018.[131] The plan focuses on reducing the total emissions of major air pollutants, and reducing greenhouse gas emissions, particularly in the Beijing-Tianjin-Hebei region, the Yangtze River Delta region, and the Fenwei Plain (Shaanxi and Shanxi) region, reducing the concentration of PM2.5 and the number of days of heavy pollution, and improving the quality of ambient air. This is the first time to include Shaanxi and Shanxi as targeted regions.

Textbox 2-1: the main targets in the Three-year Blue Sky Action Plan

- By 2020, the total emissions of sulphur dioxide and nitrogen oxides will be reduced by at least 15% versus 2015;
- For city-level administrative areas that failed to meet the 2017 PM2.5 targets, the 2020 concentration should be more than 18% lower than that of 2015;
- Over 80% days should have superior air quality (for PM2.5, defined as under 75 µg/m3) for prefecture level and above. The ratio of heavy pollution days should fall by more than 25% compared with 2015;
- Outdated coal-fired power stations under 300 MW should be closed—this may represent as much as 250 GW of capacity—though they can be replaced by new coal plants under the plan.

2.10 Conclusion

In 2018, China's energy structure has become more diversified, and the efficiency of the whole system improved. Although coal still dominates energy consumption, this is gradually changing, and natural gas has become a new growth point for fossil fuels. The non-fossil energy proportion of primary energy consumption has increased, and is on track to meet the 2020 target. However, as the next chapter illustrates in detail, there still remain many major tasks to accelerate the country's clean energy transition

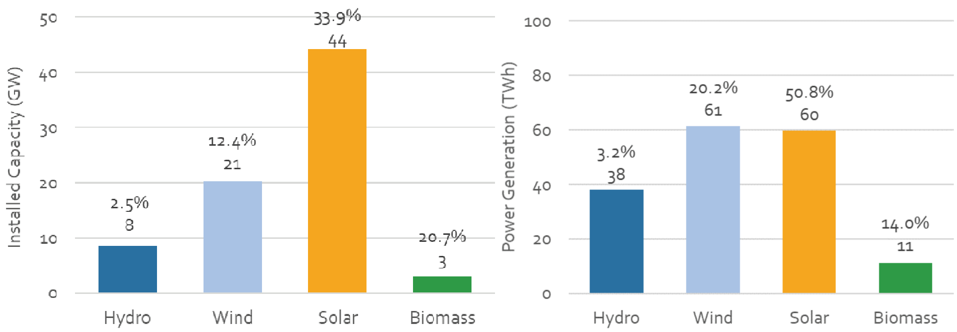
.

3. Renewable energy in China – status and obstacles

China continues to add renewable energy at a rapid pace, while also advancing reforms to its electricity and energy sectors. Nevertheless, renewable energy in China continues to face a number of policy and market barriers that slow its adoption and hinder its efficient integration. This chapter summarises these developments and obstacles.

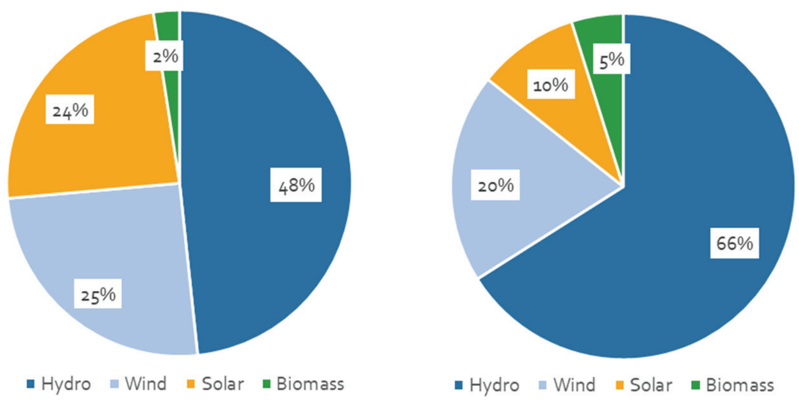
By the end of 2018, China had installed 728 GW of renewable power capacity, renewable power resources produced 26.7% of total electricity generated, an increase of 0.4 percentage point compared to 2017.[132] Compared to 2017, the country's electricity sector has grown its renewable capacity by 12%, while renewable electricity generation increased by 10%. China installed 8.54 GW of additional hydropower capacity in 2018, and cumulative hydro capacity reached 352 GW. Wind, solar, and biomass also increased.

Figure 3-1: 2018 Incremental installed renewable capacity (left); 2018 Incremental renewable power generation (right)



Source: Hydro data from China Electricity Council (CEC), January 2019; other data from China National Renewable Energy Centre (CNREC), March 2019

Figure 3-2: 2018 Grid-connected renewable capacity (left); 2018 renewable power generation (right)



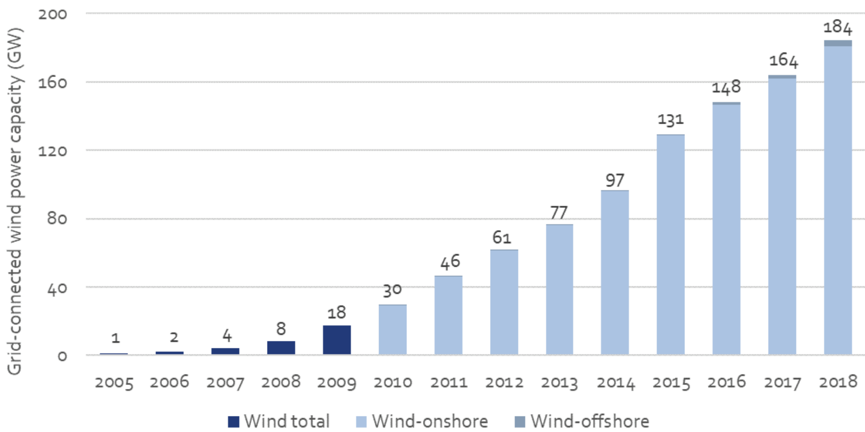
Source: Hydro data from CEC, January 2019; other data from CNREC, March 2019

3.1 Wind and solar PV

Wind

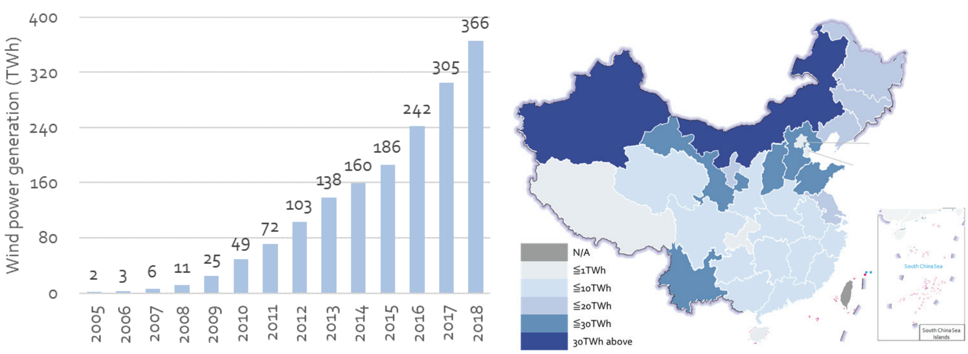
Wind power development diversifies regionally. In 2018, China added 20.59GW of wind capacity, and cumulative grid-connected wind power installed capacity reached 184.26 GW, increasing by 12.4% compared to 2017. The five-year compound annual growth rate of grid-connected wind capacity from 2013 to 2018 was 19.2%. In 2018, 47% of newly-added wind was located in the Eest Central and South China areas, diversifying wind power development across more of the country.[133] 2018 also saw 1.61 GW of new offshore wind capacity installed and connected. Cumulative offshore capacity almost doubled, reaching 3.63 GW, or just under 2% of China's total wind capacity. Wind electricity generated reached 366.0 TWh in 2018, accounting for 5.2% of China's total electricity generated. Average wind power utilization hours in 2018 rose to 2,095, an increase of 147 hours compared to 2017.

Figure 3-3: 2005-2018 China grid-connected wind power capacity (GW)



Source: CNREC, March 2019

Figure 3-4: 2005-2018 China wind power generation (left); 2018 China wind power generation by province (right)

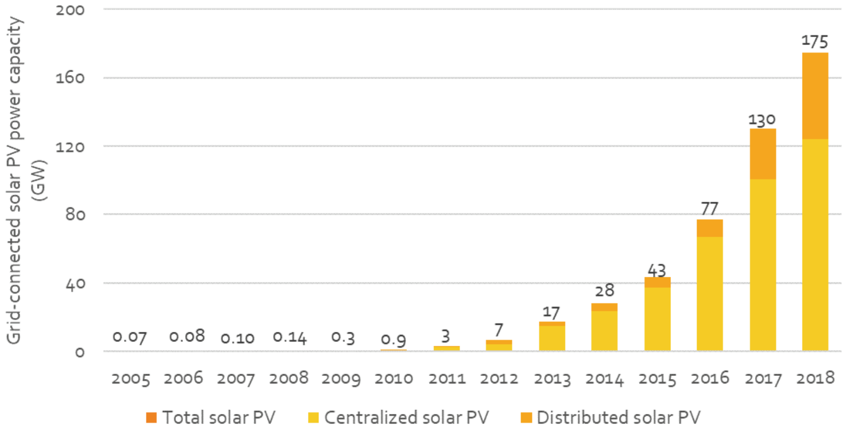


Source: CNREC, March 2019

Solar PV

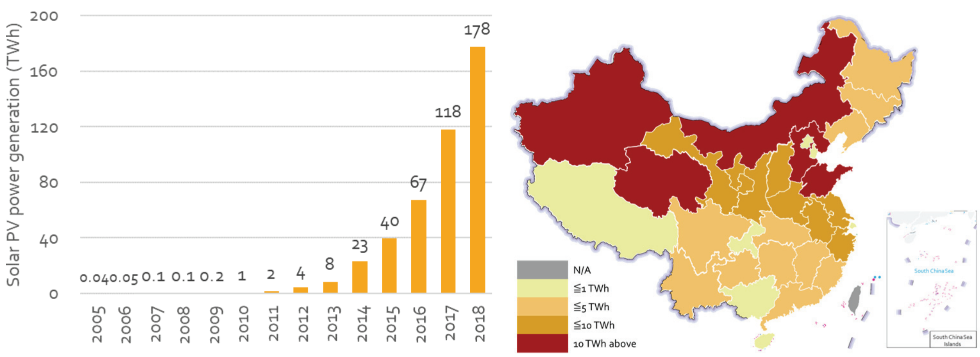
Solar PV capacity growth moderates. In 2018, China added 44.3 GW of new solar PV capacity, and cumulative grid-connected solar PV installed capacity reached 174.63 GW, increasing by 33.9% compared to 2017. Partly as a result of the 531 (May 31) solar policy, which reduced the allowed capacity for feed-in-tariff-qualified solar PV, additions of new solar dropped 16.5% in 2018 versus 2017. Distributed PV represented 47.4% (21 GW) of new additions, a 71% year-on-year growth rate for distributed PV. Newly added solar capacity in West China rose by 7.8% in 2018 due to implementation of the poverty alleviation policy.[134] 2018 also saw a huge increase in solar power generation, which surged 51% to 177.5 TWh, accounting for 2.5% of China's total power generation. Average solar PV utilization hours in 2018 rose to 1115, a decrease of 89 hours compared to 2017. China's first three large-scale, commercial concentrating solar power (CSP) demonstration project, including two 50 MW facilities in Qinghai, and one 100 MW facility in Gansu, officially began operation in 2018.[135]

Figure 3-5: 2005-2018 China grid-connected solar PV capacity (GW)



Source: CNREC, March 2019

Figure 3-6: 2005-2018 China solar PV power generation (left); 2018 China solar PV power generation by province (right)



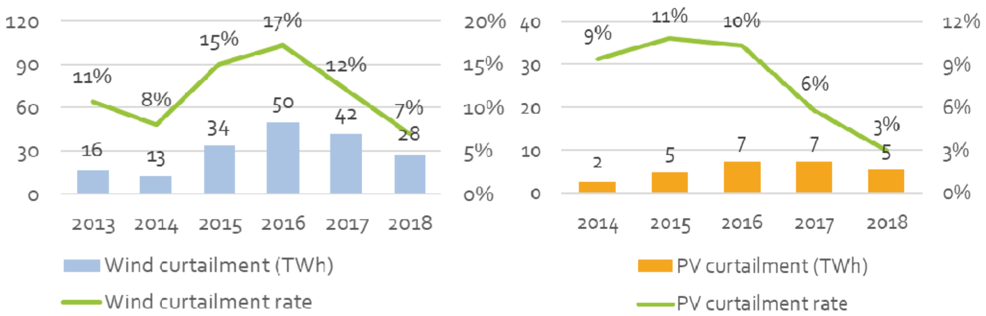
Source: CNREC, March 2019

Wind and solar curtailment

Wind and solar curtailment continue improvement trend. In 2018, China experienced wind power curtailment of 27.7 TWh, a 7% curtailment rate nationally, representing a 5-percentage-point improvement versus 2017. The majority of regions with severe curtailment have seen improvement: wind curtailment rates in Jilin and Gansu decreased more than 14 percentage points in 2018, while Inner Mongolia, Liaoning, Heilongjiang and Xinjiang experienced a reduction of more than five percentage points.[136] Shaanxi, Shanxi and Yunnan no longer have meaningful curtailment. However, wind curtailment rates are still high in Xinjiang (23%), Gansu (19%), and Inner Mongolia (10%); these three provinces accounted for 84% of wind curtailed in 2018. [137]

In 2018, China saw solar power curtailment of 5.49 TWh, or 3% nationally, 2.8 percentage points less than in 2017. Xinjiang reduced solar PV curtailment by 6 percentage points and Gansu curtailment declined by 10 percentage points, but their curtailment rates remained high: 16% in Xinjiang and 10% in Gansu.[138]

Figure 3-7: Historical wind and solar PV curtailment situation



Source: National Energy Administration (NEA), accessed in April 2019 [139]

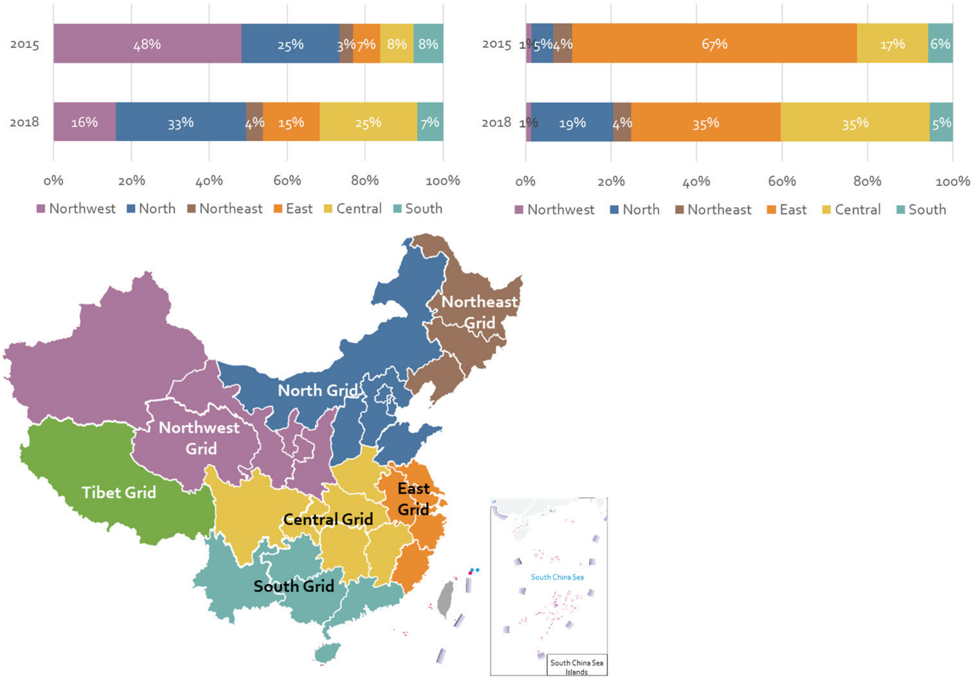
Development process from 2005 to 2018

Major development regions shift from west to east

Wind and solar in China have suffered severe curtailment for several reasons. Wind and solar plants, which were initially built mainly in relatively remote regions, take less time to approve and build than transmission. The lack of a spot power market, barriers to inter-provincial power trading, and inflexible dispatch of thermal power also contributed. The 13th Five-Year Plan (2016-2020) called for improved integration of renewable energy. These efforts, combined with limits to wind and solar additions in some provinces, has shifted wind and solar PV development closer to load centers in the eastern regions. Distributed renewable energy (defined as plants closer to load, under 50 MW and connecting at or less than 110 kV for wind power projects, or under 6 MW and connecting at or less than 35 kV for solar PV projects) has grown in parallel with central renewable capacity—particularly PV, which has benefited in recent years from higher feed-in tariffs.[140]

Compared to 2015, the share of cumulative grid-connected wind power capacity in the central, eastern and southern regions increased by 9.4 percentage points to 34.2% in 2018, while power generation increased by 5.9 percentage points to 33.9%.[141] For solar PV, the share of grid-connected installed capacity in these regions increased by 10 percentage points each year in 2016 and 2017. Half of the provinces added more than 1 GW of grid-connected distributed PV capacity in total.

Figure 3-8: 2015 and 2018 regional proportion of incremental grid-connected wind capacity (top left) and distributed solar PV capacity (top right); categorization of regional power grids (bottom)

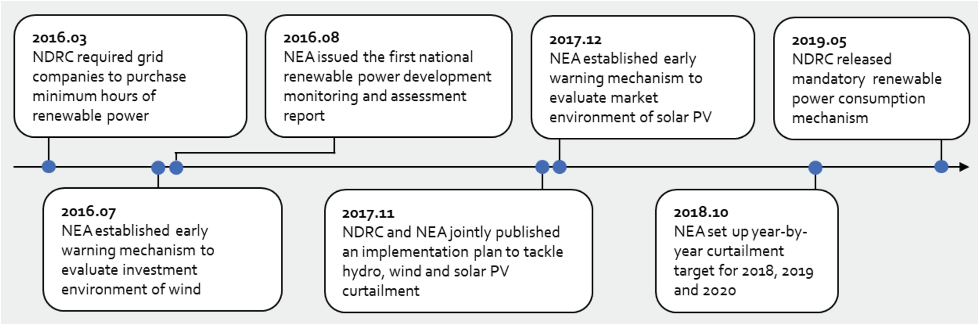


Source: (top left) 2015 data from NEA, February 2016; 2018 data from NEA, February 2018 and January 2019; (top right) 2015 data from NEA, February 2016; 2018 data from NEA, March 2019; (bottom) China Electric Power Planning and Engineering Institute (EPPEI), accessed in August 2019

Renewable energy consumption continues to improve

China also effectively controlled the pace of newly installed capacity and mandated increased on-grid capacity and consumption capabilities for renewable energy during the 13th Five-Year Plan period. The central government determined year-by-year curtailment control targets and major measures from planning to supervision.[142] On the supply side, NEA established a red-orange-green three-level early warning mechanisms to evaluate the market and investment environment of wind and PV. It required suspension of new projects in regions marked as *red*.[143] Meanwhile, grid companies were mandated to purchase certain amounts of renewable power at the price of renewable benchmark FiTs, up to annual quota amounts set by the central government for each province or municipality.[144] On the demand side, electricity retailers and customers were required to consume minimum shares of renewable power.[145] NEA would publish an annual assessment report to supervise the achievements or each province.[146]

Figure 3-9: Development of polies for renewable energy consumption



Source: NEA and National Development and Reform Commission (NDRC), accessed in July 2019

China has begun to shift from fixed feed-in tariffs to tendering and subsidy-free renewables

China's wind and solar scale-up began after the *Renewable Energy Act Law* in 2005, before which hydropower constituted the country's only major renewable power source.[147] The adoption of feed-in tariffs for wind in 2009 and solar PV in 2011 resulted in a rapid increase in onshore wind and utility-scale solar PV.[148] West China, Inner Mongolia, and Northeast China became the major wind development areas due to their superior wind resources.

In 2006, the NDRC established the policy framework for renewable feed-in tariffs, which include a subsidy paid from a surcharge on the retail electricity tariffs of all electricity consumers apart from residential and agricultural users. The renewable FIT has been the most important renewable energy incentive policy in China.[149] The NDRC Pricing Department adjusts wind and solar FITs occasionally. FIT rates vary by region, and include separate rates for distributed solar and CSP.[150]

Figure 3-10: History of the renewable surcharge (RMB/kWh)

Source: NEA, accessed in April 2019[151]

Starting in 2015, the government began to explore more market-based methods for setting renewable FiTs. In 2016, the NDRC and NEA issued policies that allowed all utility-scale PV projects to participate in tenders. As a reward for regions that have used competitive bidding to reduce FiT subsidy payments, the government grants proportionally higher annual provincial PV construction quotas.[152] This policy is designed to lower costs and reduce the subsidy burden and has partially achieved these objectives.[153] In the last three years, the Top-Runner program ,which promotes construction of PV plants with advanced, high-efficiency PV technologies, has also employed tenders to determine the on-grid tariff of each project.[154] The program has held three tendering cycles so far, each of which has shown a price decline. The average subsidy requirement for the third round commercialised-technology Top-runner PV project is below RMB 0.1/kWh, and the lowest reached RMB 0.02/kWh.[155] In addition, the government provides tax incentive policies to renewable power projects such as partially exemption on value added tax (VAT) and corporate income tax.[156] NEA also requires local governments to avoid charging unreasonable land fees in order to reduce land cost of renewable projects.[157]

Table 3-1: Commercial technology Top-Runner on-grid tariffs versus utility-scale solar PV FiTs

RMB/kWh	2015	2016	2017	After July 2018
Top-runner on-grid tariffs	0.95	0.51-0.83	0.32-0.51	
Utility-scale solar PV FiTs	0.90-1.00	0.80-0.98	0.65-0.85	0.5-0.7

Source: NEA, accessed in April 2019

Wind and solar are almost competitive with coal

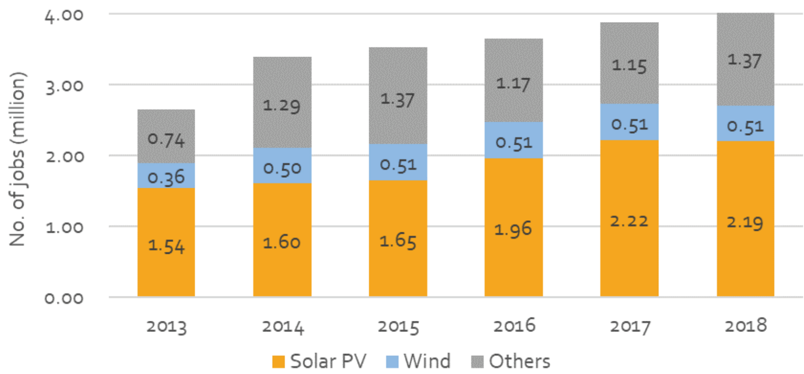
The rapid scale-up of wind and solar in China and worldwide has reduced costs for these technologies. From 2008 to 2018, levelised costs (LCOE) of wind power in China dropped by 15% to 20% (up to 25% in regions with good wind condition) and initial investment of solar PV dropped by 90%.[158] Wind and solar both are at the end of their subsidy support phase. According to CNREC, the cost of wind power is around RMB 0.5/kWh in regions with typical wind conditions, and as low as RMB 0.35/kWh in the windiest regions. Assuming these levelised costs for wind projects, and no change to coal tariffs (which presently exclude the full external cost of coal power), wind subsidies would need to range from RMB 0.07-0.08/kWh.

Similarly, solar PV has achieved the 2020 target of price competitiveness with the retail electricity price in 2018. In the first half of 2019, its levelised cost declined to approximately RMB 0.37-0.51/kWh. Solar PV will only need one or two years to be cheaper than wind.[159] CNREC forecasts that costs for these technologies will continue to decline, and it is possible that by 2020 the levelised cost of wind and solar will be below the present on-grid tariff of coal power.[160]

Employment in wind and solar PV industries remains steady

According to the earliest data of IRENA estimates, China has had the largest number of jobs in global renewable energy sector since at least 2013. The number increased from 2.64 million in 2013 to 4.08 million in 2018, accounting for 43% of the world's total.[161] In 2018, although solar PV industry had the biggest proportion of 54%, the absolute number dropped from 2.22 million jobs to 2.19 million. This is because the incremental solar PV capacity saw a drop of 15.1% in 2018 due to the reduction of the utility-scale PV construction quota. Government policies reducing FITs and imposing caps on subsidized distributed solar also have led to the change. Employment in the wind sector is roughly the same compared to 2017 at 510,000. The government imposed a stricter bidding process and lowered subsidies, which may reduce the incentive for companies to hire. Though China led the installation of offshore wind energy in 2018 at 1.61 GW, this did not translate into much domestic employment since parts were largely imported. The operation and maintenance market in wind power sector is expected to expand with increasing installed capacity in the future, CNREC believes this will bring more jobs.[162]

Figure 3-11: 2013-2018 renewable energy jobs in China



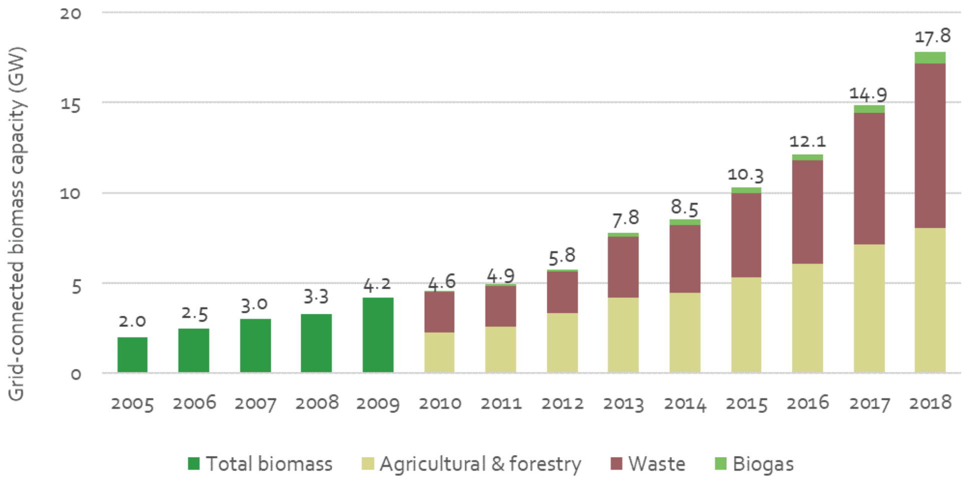
Note: Others includes biofuels, solar heating/ cooling, biomass, biogas, small hydropower, geothermal energy and CSP. Source: International Renewable Energy Agency (IRENA), June 2019

3.2 Biomass

Status

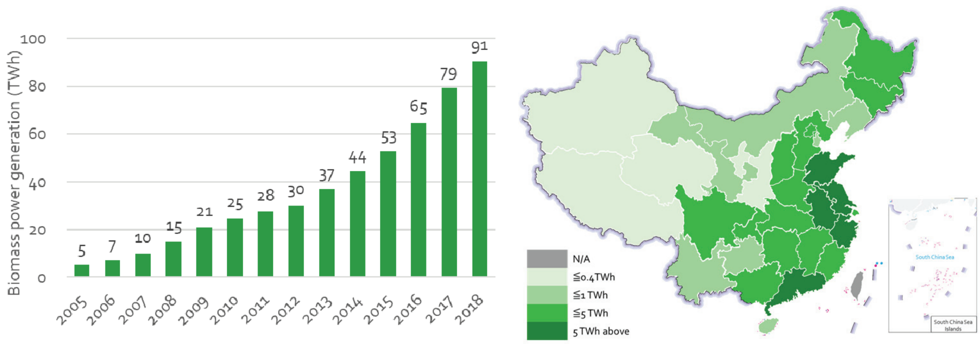
Biomass continues to grow. In 2018, grid-connected biomass installed capacity reached 17.81 GW, increasing by 20.7% compared to 2017. Newly added capacity was 3.05 GW and biomass cumulative capacity accounts for 0.9% of the total. Biomass power generation grew by 14% and reached 90.56 TWh in 2018, contributing 1.3% of total power generation. In 2018, agricultural and forestry biomass capacity grew by 12.5% to 8.03 GW, and waste incineration capacity increased by 25.7% to 9.15 GW. In the past few years, new agricultural and forestry biomass programs are located mainly in rural areas with abundant straw resources, while waste incineration programs are mainly located in urban areas. [163] Agricultural and forestry biomass combined heat and power (CHP) capacity was 2.74 GW at the end of 2017 (the latest statistics available), accounting for 39.1% of total straw biomass capacity.[164]

Figure 3-12: 2005-2018 on-gird biomass installed capacity



Note: Agricultural and forestry biomass includes straw, bagasse and forestry waste. While the statistical data of agricultural and forestry biomass excludes bagasse since 2010. Source: CNREC, March 2019

Figure 3-13: 2005-2018 China biomass power generation (left); 2018 China biomass power generation by province (right)



Note: 2005-2009 biomass includes straw, waste, biogas and bagasse, and 2010-2018 biomass only includes straw, waste and biogas. Source: CNREC, March 2019

Development process from 2005 to 2018

Biomass policies have evolved gradually since 2005. Subsidy policies are the most important incentive to support the development of biomass power since 2005. In 2006, the NDRC announced a Feed-in Premium (FiP) policy for biomass power generation projects (RMB 0.25/kWh), driving growth of both biomass capacity and generation.[165] When the sector entered a stable development period, the government shifted from a FiP to a FiT in straw biomass (RMB 0.75/kWh) in 2010 and waste incineration (RMB 0.65/kWh) in 2012.[166] Straw biomass capacity has grown steadily from 2.26 GW in 2010 to 8.03 GW in 2018, for a compound annual growth rate of 17.2%. Waste incineration also rose from 2.29 GW in 2012 to 9.15 GW in 2018, a compound annual growth rate of 26.0%, and its grid-connected installed capacity surpassed straw biomass in 2017. Due to rising urbanization rates and increased consumption, the country's total waste amount has increased quickly in both cities and rural areas, increasing the need for waste incineration. Therefore, the government is now shifting focus for this sector to towns from large and medium-sized cities.[167]

From 2015 to 2018, China has focused on biomass-CHP, which offers higher energy efficiency. In the *13th Five-Year Plan for Renewable Energy Development*, NDRC required the retrofit of existing biomass power generation projects to CHP.[168] In 2017, the NDRC and NEA set specific goals of increasing biomass-CHP capacity to over 12 GW in 2020 and over 25 GW in 2035.[169] In 2018, the NEA launched 136 county-level biomass CHP pilots; 126 of these focus on straw biomass.[170]

3.3 New renewable policies

Curtailment control targets

Government issued three-year clean energy consumption action plan. NDRC and NEA jointly announced the *Clean Energy Consumption Action Plan 2018-2020* in October 2018.[171] The plan sets out a schedule for fundamentally resolving China's longstanding problems with wind and solar energy integration, including reducing curtailment to 5% or below by 2020. For renewable energy, the policy emphasizes that new deployment of wind and solar should focus on provinces with higher consumption, given longstanding reluctance of provinces to import renewable energy from other regions. The plan also targets a 30% share of renewable in major inter-provincial and inter-regional power transmission lines by 2020. In 2018, wind, solar PV and hydro power all achieved their 2018 consumption targets on the national level.[172]

Table 3-2: Comparison of wind and solar curtailment control targets and 2018 achievement

Year	Wind usage rate	Wind curtailment rate	Solar usage rate	Solar curtailment rate
2018 Target	>88% (aim for >90%)	<12% (aim for <10%)	>95%	<5%
2019 Target	>90% (aim for >92%)	<10% (aim for 8%)	>95%	<5%
2020 Target	Aim for about 95%	Aim for about 5%	>95%	<5%
2018 Achievement	93.0%	7%	97.0%	3%

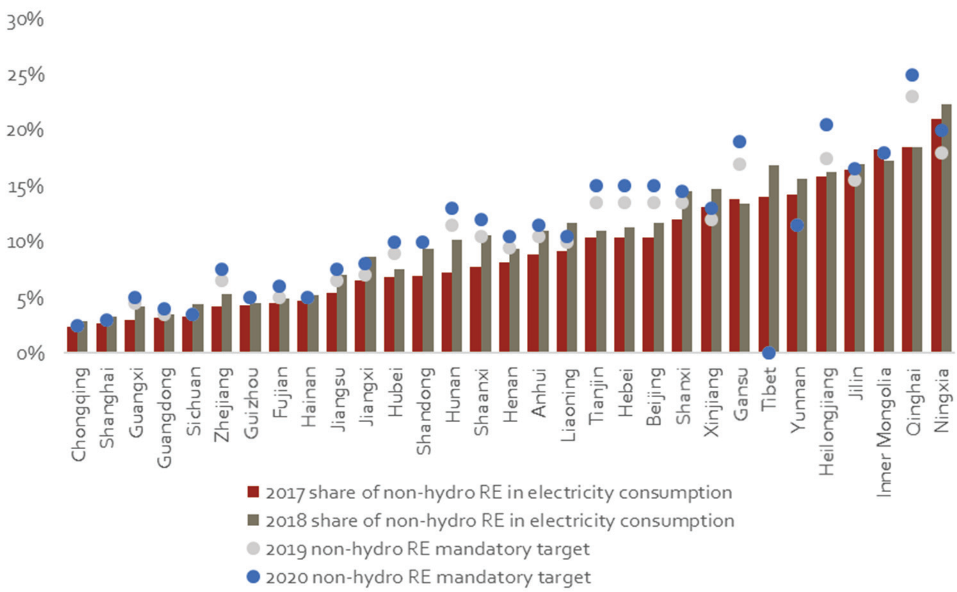
Source: NEA, October 2018

Mandatory renewable consumption mechanism

China released mandatory renewable power consumption mechanism. NDRC and NEA jointly released the *Mandatory Renewable Energy Power Consumption Mechanism* in May 2019.[173] The mechanism consists of mandatory and incentive renewable power consumption quotas for each province, requiring electricity retailers and end-users to increase renewable power consumption. Compliance entities can also meet their targets by purchasing surplus consumption of other entities or voluntary green certificates. Entities that achieve the incentive quotas can receive extra quotas for energy consumption control targets. Provincial energy administrative departments will be responsible to distribute quotas and evaluate performance. By increasing the legally binding obligations year by year, China can keep increasing the proportion of renewable consumption as a market-based tool for ongoing policy support for clean energy.[174]

Monitoring and evaluation will start from 1 January 2020. Compared to the 2020 mandatory renewable power consumption quota, 11 provinces have achieved the targets ahead of the schedule in 2018, while Qinghai, Gansu, Heilongjiang, Hebei, Tianjin, and Beijing have the biggest gaps.[175]

Figure 3-14: Comparison of 2017 and 2018 non-hydro renewable consumption with 2019 and 2020 consumption quotas

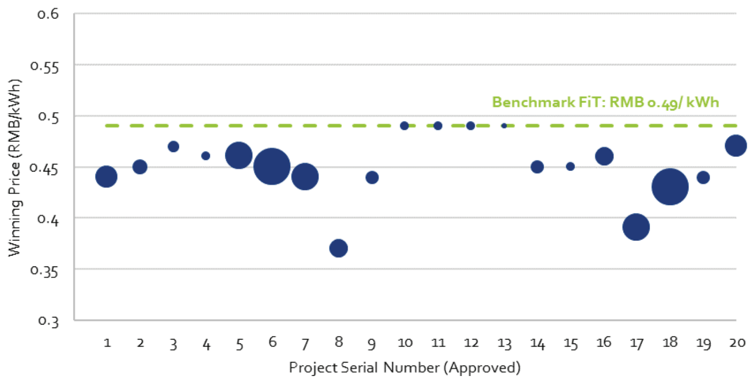


Source: 2017 data from CNREC, July 2018; remaining data from NEA, accessed June 2019

Wind power tender

New wind power projects required to participate in tenders since 2018. As NEA pushes to wind down feed-in tariffs for new projects, in May 2018, China required new provincial centralized onshore and offshore wind power projects to participate in tenders to receive construction quotas and feed-in tariff subsidies. The weight of price in assessing bids is at least 40%. In December 2018, wind-rich Ningxia province announced the bidding results for its first wind power auction.[176] The auction results show that price was not the only factor in determining winning bids.

Figure 3-15: Ningxia onshore wind power auction results



Note: Dots scaled by approved project size. Source: Ningxia DRC, December 2018

Solar PV tender

China finalised a nationwide solar tendering system. NEA implemented nationwide solar tendering since 2019, with price as the only evaluation standard. Policymakers set a subsidy cap of RMB 3 billion for solar PV projects in 2019, of which RMB 750 million is specifically for household PV, implying 3.5 GW of construction quota for this category. The allocation of the remaining RMB 2.25 billion will be determined through national tendering by utility-scale PV, industrial and commercial distributed PV. Poverty alleviation PV projects will have additional quotas. All bids will be adjusted with a price correction factor and will then be ranked nationwide.[177] Subsidized projects should connect to grid by 2019. For each quarter of delay, the subsidy will be reduced by RMB 0.01/kWh. Projects that are delayed for more than two quarters will see their qualification to receive national subsidies cancelled.

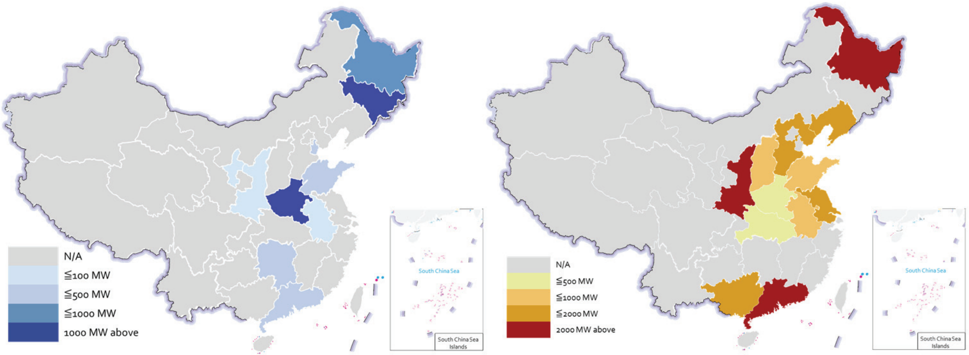
Starting in 2019 the government will determine the amount of subsidised PV projects based on electricity renewable surcharge revenue instead of planned installations. Authorities will set a subsidy cap based on the estimated incremental amount of surcharge revenue compared to 2018, which reduces the risk of insufficient funding to cover feed-in tariff subsidy payments. Tendering applies to most utility-scale PV projects, prioritising regions that will achieve subsidy-free projects. This increases the efficiency of remaining subsidies and accelerates the phase-out of subsidies. NEA issued the 2019 PV tendering results in July. It consists of 22.8 GW of projects, of which 18.1 GW is utility-scale PV and 4.7 GW is distributed commercial and industrial PV. These projects will receive subsidies after grid connection.[178]

Subsidy-free renewable program

China plans to scale up subsidy-free wind and solar projects. In January 2019, the NEA and NDRC jointly announced a plan to launch subsidy-free wind and solar pilots in regions with superior wind or solar resources and high local electricity consumption.[179] These pilots will not receive national government subsidies and the tariff must be no higher than the local benchmark feed-in tariff for coal plants.[180] However, the capacity is not limited, and the government will provide eight supporting incentives to the subsidy-free pilots such as exemption from land transaction fees and 20-year feed-in tariff power purchase agreements.[181] The pilot policy will scale up wind and solar in the most cost-effective regions, and thereby accelerate the phase-out of subsidies. China anticipates wind and solar will generally no longer receive subsidies in the early part of the 14th Five-Year Plan period (2021 to 2025).

NEA announced the first batch of subsidy-free projects in May 2019. In 20.76 GW of total capacity, 4.51 GW is for utility-scale onshore wind, 14.78 GW for utility-scale PV, and 1.47 GW for distributed renewable market trading pilots.[182] The majority of projects are expected to operate in 2020. Northeast China has the largest amount of subsidy-free projects, because with relatively lower grid-connected wind and solar PV capacity, the it has better grid access for new projects.[183]

Figure 3-16: 2019 Wind (left) and PV (right) subsidy-free pilots



Source: NEA, May 2019

Power market instruments

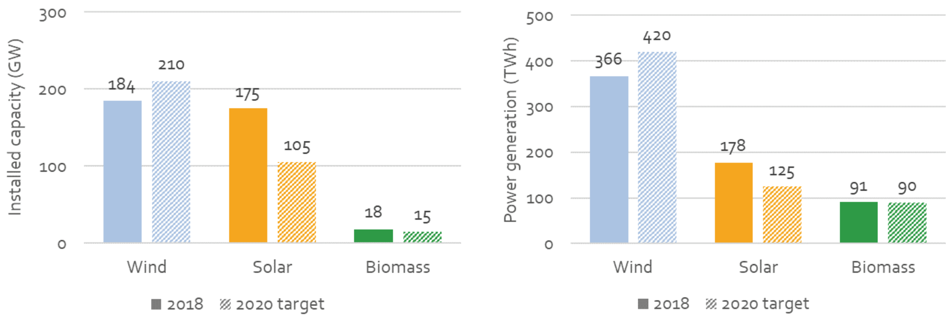
Policymakers aim to facilitate renewable energy participation in power markets. The government strongly encourages distributed renewable energy to participate in various power markets. In April 2018, NEA issued policies to specify the definition and regulatory measures for distributed wind power. The upper limit of a single project is 50 MW and it should be connected to the grid at 110-kV and below. NEA allows distributed wind power project to directly sell electricity to users within the distributed grids.[184] Later, in March 2019, the NDRC issued a draft policy for comment: Suggestions for Establishing Spot Power Market Pilots. The policy proposes that clean energy could participate spot markets by making offers for volume only (that is, without bidding a price). As price takers, renewable projects will have priority for market clearance.[185]

3.4 Trends in 2019 and 2020

Wind and solar PV

China will add around 70 GW wind and solar annually by 2020. Both solar PV and biomass on-grid capacity have exceeded their 13th Five-Year Plan targets for 2020 at the year-end 2018. In 2019 and 2020, CNREC projects China's annually added power generation capacity should be 25 GW to 30 GW for wind and 40 GW and above for PV.[186] In 2019, China will focus on three major renewable policies: implementing tenders nationwide for subsidised projects, scaling up subsidy-free wind and solar PV projects, and prioritising renewable energy utilization in both regulated conditions and in power markets. In the long-term, wind and solar will dominate power supply in the power sector under this scenario.[187]

Figure 3-17: 2018 and 2020 target of wind, solar and biomass capacity (left) and power generation (right)



Source: 2018 data is from CNREC, December 2018; 2020 targets are from NDRC, December 2016

Offshore wind

China will accelerate offshore wind. Under the 13th Five-Year Plan for Wind Power Development, by 2020 China should have 5 GW of offshore wind installed and 10 GW of wind under construction. The government has focused on the four coastal provinces in the southeast—Jiangsu, Zhejiang, Fujian, and Guangdong—which have high growth in electricity consumption. Guangdong's present consumption fulfilled less than 70% of its renewable consumption quota assigned in 2016, and the provincial government has issued a long-term offshore wind development plan (2017-2030) to fully accelerate the market.[188] Offshore wind power costs are expected to decline as the industry scales up. As a result of these factors, China should reach 8 GW installed offshore wind by 2020, compared to 3.63 GW at the end of 2018.[189]

Biomass

Biomass will still rely on FiTs. Based on present trends, CNREC expects biomass FiTs are unlikely to decrease in the near future because the levelised cost of biomass power will likely rise through the 2020's. CNREC estimates that the levelised cost of agricultural and forestry biomass will be around RMB 0.64/kWh, or RMB 0.1/KWh higher than 2017; and waste incineration power projects will be around RMB 0.81/kWh in 2020, increasing RMB

0.1/KWh compared to 2017 due to the cost of biomass inputs, and rising investment and operational cost required to comply with emissions regulations. Biomass CHP is the main trend underway. With the exception of retrofitting existing biomass power projects, to contain subsidy costs and maximize energy efficiency, policymakers may restrict the expansion of biomass projects that only generate power. [190]

3.5 Major challenges

Overall, renewable energy development has encountered setbacks at the national, regional, and individual levels. On the national level, the implementation of the mandatory consumption mechanism remains unclear. The lack of flexible resources, up-to-date energy and power systems planning, renewable electricity consumption has become a long-standing challenge. Subsidy payment delays, interference in market trading and pricing by local governments, and increasing soft costs all bring risks for renewable projects. Some local governments have banned companies from building new distributed generation in light of previous ill-considered projects, while some demand unreasonable taxes and fees from renewable projects to boost local revenue.

Renewable electricity consumption

To reduce coal consumption and increase the proportion of clean energy, China must continue to increase renewable installed capacity and electricity generation. According to CNREC projections, in 2019 China will add around 70 GW of new wind and solar PV capacity. Unless reforms continue to keep pace with these additions, enabling full consumption of renewable energy, curtailment could increase. [191]

China has yet to fully incentivise important institutional players to prioritize renewable consumption. The western and northern regions have large-scale wind and solar PV, but these regions historically focused on capacity expansion over planning and construction of transmission lines or improving provincial consumption. Most of the central and eastern provinces still rely on local thermal power and do not fully give market space for renewable energy production.[192] Although the government has established a binding consumption mechanism, the long-term implementation path is still unclear. By 2018, there was still a gap of 3.5% to 6.5% between the 2020 provincial binding targets of non-hydro renewable energy consumption and the actual consumption ratios in Qinghai, Gansu, Heilongjiang, and the Jing-Jin-Ji region.[193]

The flexible resource and adjustment capability of the power system remains only partially exploited. In terms of capacity, the current proportion of flexible power supply such as pumped hydro storage and flexible gas power plants in the Three Norths is less than 2%, and especially in winter, flexible capacity is limited due to the large share and inflexible operating protocol for CHP units.[194] Wind and solar PV electricity have also increased demand for frequency regulation in day-ahead and intra-day power dispatch plans. Power dispatch centres currently set power dispatch plans based on the yearly, monthly, weekly and daily periods. This approach needs further optimization for variable renewable energy.[195]

Despite the urgency of enhancing inter-provincial and inter-regional power transmission of renewables, national long-term inter-regional transmission plans have yet to include this element, reducing local government motivation to consume renewable energy.[196] In addition, demand side management is still in the trial phase; so far there is no functional flexible load utilization mechanisms to promote renewable energy consumption.[197]

Planning also affects renewable consumption. Solar PV and wind installation targets set in the *13th Five-Year Plan for Power Development* were completed ahead of schedule in 2017 and 2018. However, the construction and operation of the power grid are still in accordance with plans set earlier, hampering export renewable electricity to consumption centres.[198] System planning and coordination among grid, generation, land use, and environmental protection represents a long-term obstacle to renewable energy integration.

Profitability of renewable projects

The development of wind and solar PV has gradually entered a post-subsidy era. Yet although wind and solar PV have reduced capital costs, revenue declines, added external costs, and increased uncertainty have hampered renewable developers. Some provinces have established various market mechanisms, yet the actual tariff is mainly based on the local government's guiding price, and some on-grid tariffs may be as low as a few cents per kWh. This reduces realized income of projects, in turn making it more difficult to reduce subsidies. The cost of ancillary services in the Northeast has not been transferred to users or collected from transmission and distribution tariffs; rather, renewable projects absorb these costs.[199]

Regulatory restrictions on land use, environmental impact assessments, soil and water conservation have become stricter, and this has increased costs for new renewable projects. In 2018, non-technical costs accounted for 30% of the total installed cost of utility-scale solar PV plants in China, versus 16% in Germany, 22% in the United States, and 24% in India.[200] Although VAT regulations are clear, regulations setting the farmland occupation tax, land use tax, and water resource fees for renewable projects, local implementation often varies, creating additional hurdles. For instance, in the *Provisional Regulations on Farmland Occupation Tax issued by the State Council in 2007*, the scope of urban farmland occupation tax is given a 20-fold interval tax rate, giving local governments wide discretion to set taxes at prohibitive levels.[201]

During the 13th Five-Year Plan period, incremental wind and solar PV capacity began to shift to the central and coastal regions based on national policy guidance. This has shifted attention to the problem of high land cost. Solar PV developers should pay the farmland occupancy tax all at once and pay the land use tax every year. However, the land use tax in differs greatly by city: in some eastern cities and towns, the annual land use tax exceeds RMB 1000/mu.[202] In addition, some local governments require solar PV developers to pay 20 years of land use tax all up front, severely challenging investment cash flow returns.[203] Another issue is that ministries have different classification for land types, leading to a back-and-forth negotiation among government departments for land use approval, extending the investment and development cycle and increasing uncertainty. For instance, part of the unused land and wasteland listed in the planning documents of the former Ministry of Land and Resources was defined as forest land in the planning documents of the former State Forestry Administration, preventing the use of this wasteland for solar PV plants.[204]

Existing renewable power projects face risks from delayed subsidy payments and price competition in power markets. Since 2012, the government has paid more than RMB 400 billion in subsidies for renewable electricity via the Renewable Energy Development Fund, derived from electricity surcharge funds. Because wind and solar have developed rapidly in the last five years, while the funds collected from the Renewable Surcharge have not kept pace, the cumulative surcharge deficit in 2018 exceeded RMB 160 billion.[205] Subsidy payment delays may last through the 2020s, leading to financial risks for renewable project developers and hindering involvement of private sector players, ultimately leading to higher costs. In addition, the current coal power price does not fully count external costs.[206] Given these circumstances, wind and solar must achieve even lower prices to compete with conventional fuels without subsidies.

Distributed generation

Development of distributed generation faces both market and regulatory issues. NEA announced plans to establish liberalized trading markets for distributed generators and consumers within distributed grids in 2017, but only a small number of pilots had kicked off by 2018, partly due to issues related to transmission and distribution (T&D) tariffs.[207] T&D prices range from RMB 0.001/kWh to RMB 0.3/kWh, which is either too high or too low to represent the real costs of power transmission and distribution. The absence of either effective electricity markets or reasonable grid-utilization pricing prevents many distributed generators from selling electricity directly to end-users and consequently reduces or eliminates their competitiveness.[208]

Second, the management and supervision of land use and environmental impacts of distributed renewable projects are under control of different local departments, making it difficult to implement projects. Due to unclear departmental regulatory functions and changing local land use policies, renewable projects have in some cases been demolished following construction, while other projects have been denied grid connection after completing construction. Meanwhile, renewable developers have lacked guidance and monitoring, and hence illegally built projects on wetlands, farmlands, or on the foundations of condemned buildings.[209] To avoid these problems, some local governments have banned all companies from building any new distributed generation.[210] Land occupation larger than expectation and potential adverse impacts on crops and animals are also concerns raised by local governments.

3.6 Conclusion

China has made substantial progress on scaling up renewable power as well as reducing the cost of renewable energy in the past 20 years, and as a result China has fulfilled the 13th Five-Year Plan targets ahead of time. Wind and solar PV have gradually entered the post-subsidy era, and nationwide subsidy-free and FiT tendering projects will be the new trend. In 2018, the government promoted consumption of renewable energy via setting mandatory caps on curtailment and minimum consumption targets. Nevertheless, obstacles such as subsidy payment delays and unclear land use policies still remain. More long-term targets and measures are needed to meet the challenges and maintain healthy industrial development.

Part2:
Energy Scenarios for 2035 and 2050

4. Energy scenarios to 2050

The renewable energy outlook for China uses scenarios to analyse how renewable energy can be used in the Chinese energy system. The scenarios provide a clear and consistent vision for the long-term development as basis for short-term decisions. Two scenarios are defined: The *Stated Policies scenario* expresses the impact of a firm implementation of announced polices, while the *Below 2 °C scenario* shows a pathway for China to achieve the ambitions vision for an ecological civilisation and the role China could take in the fulfilment of the Paris agreement. On top of these scenarios, several variants are analysed to illustrate specific issues which influence the implementation strategies.

The scenarios are modelled in detailed bottom-up models for the end-use sectors and for the power sector. Specific assumptions for macroeconomic indicators, demographic indicators and targets or restrictions to the scenarios' energy systems are used as input to the models to guide the development trends in the desired direction and to ensure fulfilment of the goals for the energy system development. Within these boundaries, the power sector model is driven by an overall cost-optimisation to ensure cost-efficient energy system transformation.

This chapter explains the scenario methodology, the general ideas behind the two scenarios and the main assumptions used in the scenarios.

4.1 Scenario methodology

The scenarios are designed to achieve the following:

- Provide a clear long-term vision. The energy system composition of this vision will be presented as well as the reasoning behind.
- Establish a clear view of the current situation, trends, market and policy direction, and project this into the future.
- The forecasted trends and the long-term visions are forced to converge and form a connected story as a complete energy system scenario.

During the work with the scenarios, the gaps between the short-term direction and the long-term vision become apparent. The scenarios and their supporting models are loaded with constraints and strategic priorities to achieve a consistent connection between the short-term and long-term.

As a matter of principle, there is no claim of cost-optimality or that the presented scenarios are perfect. However, where possible, it has been attempted to quantify the costs and benefits of the scenarios and evaluate the performance of the scenarios against key policy imperatives.

As a matter of process, least-cost optimisation principles are relied upon to fill in the blanks, and as a proxy for agent behaviour within the overall policy framework conditions and constraints defined in the scenarios.

The scenario results provide input for timely policy making

The quantitative and qualitative expressions of the scenarios are inputs for policy making with three distinct frameworks:

1. Recommendations for policy approaches, policy measures and targeting setting in the 14th Five-Year Plan period (2021-2025).
2. Recommendations for the medium-term policy developments in the 15th and 16th Five-Year Plan periods (2026-2035)
3. To assist in crystallising the long-term policy objectives and targets and provide a measure of confidence, supporting long-term objectives for the realisation of bold policy visions.

4.2 Two main scenarios

CREO 2019 continues the tradition from previous outlooks with two core scenarios for the energy systems development.

Stated Policies scenario expresses firm implementation of announced policies

The scenario assumes full and firm implementation of energy sector and related policies expressed in the *13th Five-Year Plan* and in the *19th Party Congress announcements*. Central priorities are the efforts to build a clean, low-carbon, safe and efficient energy supply. The scenario also includes the *NDC* climate target to peak in emissions before 2030, the effects of the *Blue-Sky Protection Plan*, aspects of the *Energy Production and Consumption Revolution Strategy*, and the *National Emissions Trading scheme*.

Policy trends are extrapolated to set the longer-term policy drivers.

Below 2 °C scenario shows how China can build an energy system for the ecological civilisation

The Below 2 °C scenario shows a road for China to achieve the ambitious vision for an ecological civilisation and the role China could take in the fulfilment of the Paris agreement. The main driver is a hard target for energy related CO_2 emissions through a strategy with renewable electricity, electrification and sectoral transformation at the core. The target is set at 200 million tons of energy related CO_2 emissions in total between 2018-2050.

Supplementary scenario variants to illuminate specific issues
Scenario variants are used in the report to highlight or quantify in isolation the implications of alternative approaches to a specific issue. This year's CREO includes variants on the resource recycling in industries, energy saving potential based on useful energy analysis, available resource potential for distributed resources, demand response in aluminium smelters, availability of smart charging and V2G, possibility flexible coal plant investments and retrofits, transmission investments, transmission flexibility and the use of natural gas.

> The two core scenarios are compound scenarios with an array of differences in terms of the assumptions. Therefore, it is not always straightforward, or even possible, to attribute specific outcomes to specific measures included in the scenarios. The core scenarios provide a reference upon which to base a differential analysis against their scenario variants. Variants can be thought of as single parameter variations, where one of the core scenarios is recalculated, with a single alteration on the input side.

Modelling provides quantification, consistency and completeness

The scenario's development in CREO is supported by CNREC's energy system modelling tool, consisting of interlinked models, covering the energy sector of Mainland China.

The China National Renewable Energy Centre has, since it was established in 2011, focused on developing comprehensive modelling tools to analyse the energy and socioeconomic impact of development and integration of renewable energy in the Chinese energy system.

Final energy demands are directed in the END-USE model

The END-USE model, based on LEAP (Long-range Energy Alternatives Planning system), represents bottom-up modelling of end-use demand and how this demand is satisfied. End-uses are driven by assumed developments in key activity levels in the economy, including production projection of key energy intensive products (steel, cement, chemicals, etc), and the economic value added for other industries.

These drivers translate to energy consumption when combined with assumptions such as industrial output changes, floor area development, energy efficiency improvement, device and fuel shifting (mainly in industry and transportation sectors), as well as end-use behavioural features adjustment.

Transformation activities aside from district heating and power are also covered by LEAP, including upstream refinery activity, such as hydrogen production from the electrolysis process, biofuel production via different technical routines, oil-refining, etc.

Power and district heating sectors are modelled in EDO

The EDO (Electricity and District heating Optimisation) model is a fundamental model of power and district heating systems, built on the Balmorel model (www.balmorel.com). The power system is represented at provincial level, considering the interprovincial grid constraints and expansion options. The model includes all relevant production units, i.e. thermal (including CHP), wind, solar (including CSP), hydro, power storage, heat boilers, heat storages, heat pumps, etc on the supply side. Moreover, it also considers options for demand-side flexibility, e.g., from industries, smart charging of electric vehicles, as well as the option of a full integrated coupling with the district heating sector.

The model can represent the current dispatch in the Chinese power system on an hourly basis, with limitations on the thermal power plants and interprovincial exchange of power; it can also represent the dispatch in a power market, provincial, regional or national, based on the least-cost marginal price optimization. Key characteristics relate to the detailed representation of variability of load and supply (e.g. from VRE sources) as well as flexibility and flexibility potentials, which can operate optimally and be deployed efficiently in capacity expansion mode. As the Balmorel model is open-source, it has allowed for flexible customisation and enhancements including core features and 'add-ons' to tailor the model for application on China, and for interaction with CNRECs suite of models. EDO was introduced in 2012 and has been continuously used and enhanced hereafter, including in the production of the previous CREO reports.

Combined summary tool

Quantitative results from the two models are combined in an integrated Excel-based tool, which provides an overall view of the energy system, e.g. combining the fuel consumption from the power and heating systems from EDO, with direct consumption in end-use sectors and consumption in other transformation sectors from LEAP.

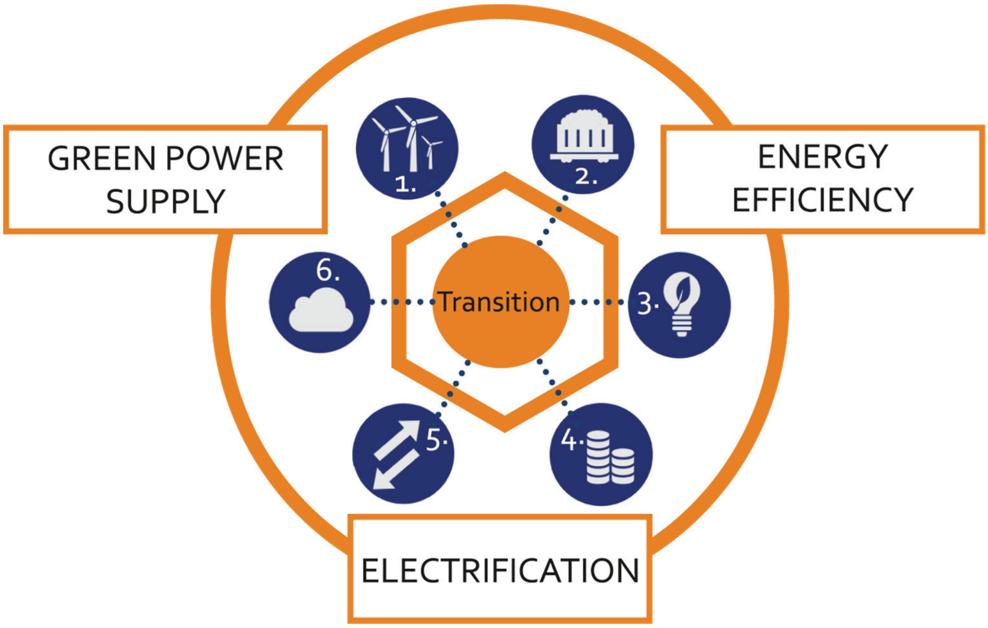
4.3 Energy transition strategy underpinning the scenarios

Economic growth is bottom line precondition of China's socioeconomic objectives for 2050. It is required that GDP grows 4.2 times from 2018 level in real terms by 2050. However, the growth shall be sustainable and supported by the transition of the Chinese energy system to build in the properties of *clean, low-carbon, safe and efficient* – and essential component in the efforts to build China's Ecological Civilisation.

The strategy for the energy transition explored in the China Renewable Energy Outlook relies on three pillars.

- **Green energy supply** – technological progress and cost reduction makes RE deployment possible to provide the clean energy in bulk, particularly through renewable electricity.
- **Energy efficiency** improvement is a key pillar on the demand-side to ensure adequacy of the pace and scale of deployments on the supply-side and support the required economic growth.
- **Electrification** and market reforms will change rules of the game on the demand-side and drive fossil fuels from end-use consumption, in conjunction with decarbonisation of the electricity supply.

Figure 4-1: Drivers of the energy transition in the scenarios



The strategy is supported by key drivers:

1. **RE promotion:** Renewable energy is promoted, and renewable electricity has a core role in the energy transition. Cost reductions in deploying renewables at scale have been tremendous and further improvements are projected. However, the supporting frameworks must be in place to ensure that development is not stymied, as subsidy support mechanisms are phased out.
2. **Coal control:** Coal is the main culprit of China's environmental challenges and greenhouse gas emissions. Production and consumption controls must be firm and tightened. Limits on coal consumption are set in the scenarios as boundary conditions.
3. **Energy efficiency measures:** The potentials for energy efficiency improvements in China's energy system are profound and their realisation must be supported by strong policy focus. This goes hand in hand with the restructuring of the economy towards less energy intensive sectors.
4. **Power markets:** China's ongoing power market reforms shall result in significant efficiency gains, enabling electricity to be a cost-competitive energy carrier for an increasing number of energy consumption applications. With the expansion of variable power generation from wind and solar, the dynamic short-term power markets will be particularly needed to ensure deep participation of supply and demand-side resources, as well as efficiently coordinated grid operations, to support integration.
5. **Flexible power system:** Variable wind and solar generation will become the crux of the power system, changing the paradigm of power system operation

substantially. Flexibility is a prerequisite for large scale wind and solar integration. The transition is cost-efficient through utilization of all cost-effective sources including generation, demand, grid and storage.

6. **Efficient carbon control policy:** To reduce carbon emissions and deliver on the commitments to the Paris agreement, it is essential to build out and strengthen the policy framework to control carbon emissions. Pricing and control of carbon emissions is promised to be guided by market forces under the national emissions trading system being piloted in the power sector, which shall be expanded to cover all of China's main emitting sectors.

4.4 Main assumptions

The main assumptions in the scenarios are described in three tables in the following.

The overall assumptions for macroeconomic indicators, demographic indicators and targets or restrictions to the scenarios' energy systems are presented in Table 4-1.

Table 4-1: Overall assumptions and restrictions

	Stated Policies scenario	Below 2 °C scenario
Population	Population of 1.38 bn in 2050.	
Economic development	Economic growth from RMB 90 trillion in 2018 to RMB 380 trillion by 2050.	
Urbanisation rate	The process of urbanisation in China will continue to be an important factor. From the 2018 level of 59.6% according the National Bureau of Statistics, urbanisation should increase to 70% by 2030. According to ERI assumptions, 78% of citizens should be urbanised by 2050	
Primary energy consumption limit	Growth in primary energy consumption should be controlled. By 2020, primary energy consumption should remain below 5 bn tce based on the 13th FYP. By 2030, the primary energy consumption should be below 6 bn tce, following the Energy Production and Consumption Revolution Strategy. The vision for 2050 states that primary energy consumption should stabilise beyond 2030 until 2050.	
Limit coal consumption	Coal consumption in 2020 should account for less than 58% of the primary energy consumption, according to the 13th FYP. The scenarios restrict coal consumption to 1 billion tons of coal (714 million tce) by 2050, according ERI assessment of the boundaries for an environmentally sustainable energy system for China.	
Security of supply	The energy supply should be diverse and the dependence on imported fuels should be significantly reduced.	

Energy intensity per unit of GDP	The 13^{th} FYP sets the target of reducing energy consumption intensity by 15% in 2020 relative to 2015. In the scenarios, the energy intensity shall be reduced by 85% relative to 2018 (base-year)	
Non-fossil proportion of primary energy supply	The 13^{th} FYP sets the target of non-fossil proportion of 15% in 2020 and 20% in 2030. The Energy Production and Consumption Revolution strategy further states that by 2050 more than 50% of primary energy supply should come from non-fossil sources. However, in order to achieve emission reduction targets to successfully develop the ecological civilisation, non-fossil energy must account at least two thirds of primary energy supply by 2050 in the scenarios.	
Carbon emission constraint	China's official target in the NDC and other policy documents is that the carbon intensity shall decrease by 40%-45% and 60%-65% by 2020 and 2030, respectively, relative to 2005.	Based on the carbon emission limit set by the simulation results of the Intergovernmental Panel on Climate Change (IPCC) database, a 66% confidence rate can control the temperature rise below two degrees. Cumulative emission from 2018-2050 should be limited below 200 billion tons, and 2050 emissions should be less than 2500 million tons.
Natural gas targets	The 13^{th} FYP sets the ambition to increase natural gas' proportion of the primary energy supply to 10% by 2020. The Energy Production and Consumption Revolution Strategy set the ambition of 15% of natural gas in the energy mix by 2030. Natural gas will further expand in the short-term but is required to peak in 2040 in either scenario, and subsequently recede to be replaced by non-fossil sources. Due to the difference in primary energy consumption in the scenarios, the absolute levels of natural gas consumption differ, and boundaries are set on absolute terms in each.	
	The peak in 2040 is in the range 630-650 bcm	The peak in 2040 is in the range 580-600 bcm
Electrification rate	The 13^{th} FYP sets the target 27% for electrification rate by 2020. As a core pillar of the energy transition strategy, electrification shall be increased significantly.	
	>50%	>60%

These assumptions frame the overall boundaries and strategy objectives to be achieved in the scenarios. The indicators have the role of providing top-down guidance during the process of developing the scenarios. How these targets and indicators affect the overall scenarios is described in further details in Chapter 5, where the main results for 2035 and 2050 are presented. Chapter 10 focuses on the short- and medium-term implications.

The energy transition begins with transformation in the way energy is used.

The key indicators guiding the development of scenarios' end-use consumption, are provided in Table 4-2.

Table 4-2: End-use sector guidance

	Stated Policies scenario	Below 2 °C scenario
Industry	**Phase out excess capacity**: by 2050, the output of steel decreases by 27%; the output of cement decreases by 50%.	
	Resource recycling: Share of scrap-based steel reaches 50 % by 2050; share of recycled aluminium reaches 45% by 2050.	Share of scrap-based steel reaches 65% by 2050; share of recycled aluminium reaches 58% by 2050.
Transportation	Per capita ownership for private cars increases by 60% in 2035 and by 120% in 2050.	
	ICE ban for passenger light-duty vehicles shall be introduced by 2050.	ICE ban for passenger light-duty vehicles shall be introduced by 2035.
	Non-road passenger transport turnover increases by 30% by 2050. Increase in passenger transport by rail and air shall be 200% and 180%, respectively, by 2050.	
	Freight transport turnover increases by 80 % until 2035, and 115% by 2050, relatively to 2018. The proportion of freight modes by on-road, rail and sea shifts from the current 48%, 20% and 32% to 32%, 30% and 38% by 2050.	
	New energy vehicle (NEV) market share of light trucks is set to reach 12% by 2035 and 24% by 2050.	NEV market share of light trucks is set to reach 67% by 2035 and 100% by 2050.
	NEV market share of medium and heavy trucks is set to reach 12% by 2035 and 20% by 2050.	NEV market share of medium and heavy trucks is set to reach 42% by 2035 and 75 %by 2050.
Buildings	The total floor area increases by 48% until 2035, and 70 % by 2050. The proportion of urban residential, rural residential, and commercial buildings shifts from the current 41%, 34% and 25% to 55%, 17% and 28%.	

	IDC floor area increases five-fold by 2035, and nine-fold by 2050
	Reduction of heating intensity is set 15-35% for urban residential buildings and 30-50% for rural residential buildings by 2035.
	Heating service saturation for urban residential buildings reaches 100% in 2035 in all areas.
	Increase of cooling intensity is set 15-35% for urban residential buildings and 28% for rural residential buildings by 2035.
	Cooling service saturation for urban residential buildings reaches 100% in 2035 in all areas.

Further details, results and implications are described in:

- Chapter 6, which presents the industry road map;
- Chapter 7, which presents the roadmap for transport;
- Chapter 8, which presents the road map for heating.

Finally, the scenarios adopt the strategy that the crux of the energy system transformation is the development of non-fossil and renewable energy, which primarily is implemented through the power sector. The key indictors underpinning this scenario strategy are listed in Table 4-3.

Table 4-3: Key assumptions for development of the power sector

	Stated Policies scenario	Below 2 °C scenario
Non-fossil proportion of electricity	In the power generation mix, a minimum target of 50% non-fossil electricity by 2030 is applied as a restriction in both scenarios, based on the guidance set in the Energy Production and Consumption Revolution Strategy.	
Energy resource potential and long-term targets	Considering the safety issues, only the sites for nuclear power along the coast is considered, which leads to 100-110 GW capacity in the long term. Hydro power is well developed in China, and the remaining resource has been planned to be developed in the future, mostly concentrated in Sichuan, Yunnan, Tibet and Qinghai. In total 530 GW hydro power will be gradually developed by 2050. Technical and economical feasible resource potentials of wind power and solar PV are set in the model for different provinces. The overall potential for onshore wind is 4900 GW, of which less than 2000 GW can be developed in the form of distributed wind. The potential of offshore wind is 217 GW (mostly considering nearshore). The resource potential of solar PV is 2537 GW for utility-scale PV plants, and 1633	

	GW for different types of distributed PV including BIPV and roof-top PV.	
RE subsidies	By 2020, wind should be competitive with coal fired-generation and solar should be competitive with grid electricity. Moreover, distributed solar should be competitive with the grid price.	
Carbon pricing	The price of carbon dioxide in the power sector rises from 50 yuan per ton in 2020 to 100 yuan per ton in 2030.	By 2030, the carbon dioxide emission cost of the power industry will increase to 160-180 yuan per ton, and by 2040 will increase to about 200 yuan per ton.
Power generation cost	The energy generation costs from solar and wind rapidly decline, making wind and solar more competitive. Fossil generation costs increase due to fuel costs, pricing of emissions and reduced full load operating hours. Consequently, RE can be developed at a lower price than coal-fired power in the short-term. With the further decline of energy costs and integration costs, the scale of transformation will accelerate on a system cost basis.	
	The initial investment cost (including unit, construction, taxes, etc.) of onshore wind power in 2035 and 2050 have decreased to 6200 yuan/kW and 5950 yuan/kW, respectively. Offshore wind power in 2035 and 2050 has decreased to 8900 yuan / kW and 7800 yuan / kW or less. Utility scale photovoltaic power generation in 2035 and 2050 have decreased to 2870 yuan / kW and 2460 yuan / kW, respectively.	
Electricity demand and electrification	Electricity demand reaches 6800 TWh by 2020, 9000 TWh in 2035, and 11700 TWh in 2050, when the electrification level will be 46%.	Electricity demand reaches 7 TWh by 2020, 11400 TWh in 2035, and 14000 TWh in 2050, when the electrification level will be 63%.
Demand response	It is assumed that, by 2030, demand response technology will be widely used based on the electricity market. By 2030, industrial demand response provides up to 8 GW of flexibility. By 2050, this is increased to 14 GW.	By 2030, industrial demand response provides up to 41 GW of flexibility By 2050, this is increased to 69 GW.

	Additionally, aluminium smelters provide 5 GW of DR flexible capacity in 2025, which drops to 4 and 3 GW by 2035 and 2050 respectively. By 2030 100% of electric vehicles can have their charging smartly adjusted. V2G is introduced from 2030 and by 2050 50% of electric vehicles provide V2G services and deliver power the grid when needed.
Developing well-functioning spot markets	Generation rights, such as rights awarded to generators based on a perceived fair principle of allocation between market participants and generation assets. Designed full-load operating hours according to technology types will be gradually removed and replaced by economic dispatch, which schedule the power generation based on economic merit order. Interprovincial transmission scheduling, in which flow schedules are adopted initially by setting constant levels of flow for day-time and night-time. Such fixed schedule will be further released by mobilising the flexibility among regions to achieve a larger-scale balancing. The provincial markets are put into operation before 2020. The first cross-provincial unified power markets emerge in 2022. Regional power markets based on regional power grids is formed by 2035. A unified national market is formed from 2040.

In addition to the overall targets, the modelling takes account of several specific targets and polices at national level, as well as specific provincial targets. These targets generally apply in the short-term until 2020, based for instance on 13th Five-Year Planning documents for capacity development of RE resources at provincial level and mandatory RE consumption by province[211] 2019-2020. Targets are also set for RE technologies, which are less competitive at their current stage of development, but which may become part of the technology mix in the long-run, i.e. geothermal power, concentrating solar power (CSP) and ocean energy.

Further details, results and implications regarding the power sector and presented in the power sector roadmap in Chapter 9.

5. China's energy system in 2035 and 2050

Renewables are at the core of China's long-term energy system and ensuring a rapid scale-up of deployment, investments and integration of renewables, will be central to maximising the long-term benefits of the energy transition. In this chapter, the main scenario results are presented, with focus on the medium and long-term milestones of 2035 and 2050.

5.1 A quick overview

Both the Stated Policies and the Below 2 °C scenarios emphasize China's ongoing process of energy transition. The pace of transition differs as well as the timing and level of emphasis on the deployment of different technologies.

Energy CO_2 emissions reduced by 30-45% by 2035 and by 60-75% by 2050 from 2018

From the 2018 level of 9,550 million tons of annually energy related CO_2 emissions, the Stated Policies scenario's emissions are reduced to 6,750 million tons by 2035 and 3,700 million tons per year by 2050. The Below 2 °C scenario's CO_2 emissions are reduced to 5,150 million tons and 2,600 million tons by 2035 and 2050, respectively. Cumulative energy CO_2 emission are 230 billion tons between 2018-2050 in the Stated Policies scenario and 195 billion tons in the Below 2 °C scenario.

The reductions in CO_2 emission are realised through:

- Reduction of the energy intensity of the economy through stringent focus on energy efficiency.
- Substantial decarbonisation of the power sector.
- Increased electrification of end-use consumption.
- Increased direct consumption of renewables in end-use sectors.
- Reduction of fossil fuels in end-use sectors.
- Increasing the use of natural gas in the medium term to replace coal, followed by a decline in the long-term as non-fossil sources replace natural gas.

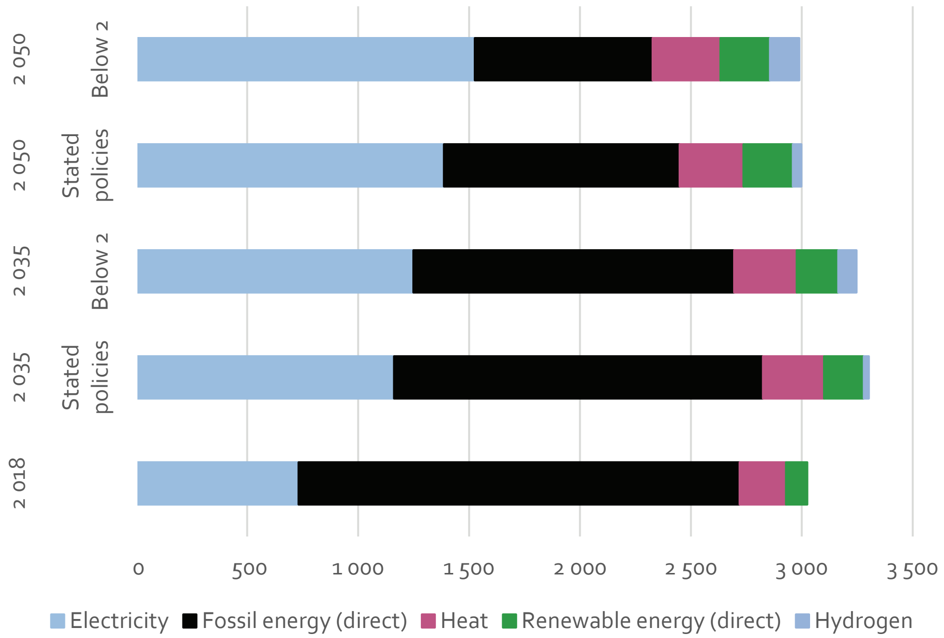
The additional reductions in CO_2 emissions in the Below 2 °C scenario arise from:

- More comprehensive decarbonisation of electricity supply through additional renewables – particularly wind and solar.
- Increased electrification of end-use sectors, and in the long-term scaling-up the use of alternative secondary energy carriers like hydrogen, further extending the reach of decarbonised low-cost power supply.
- More significant role for device shifting is taken as a means of energy saving measures.

Final energy consumption stabilises at current levels

Energy savings, together with economic restructuring, enable the 2050 total final energy consumption to be on par with its 2018 level, around 3,160 mtce/year. Until 2035, the final energy consumption increases approximately by 10% to around 3,460 mtce/year in the Stated Policies scenario and to around 3,350 mtce/year in the Below 2 °C scenario, before returning to the previous level and slightly below previous level in the Below 2 °C scenario.

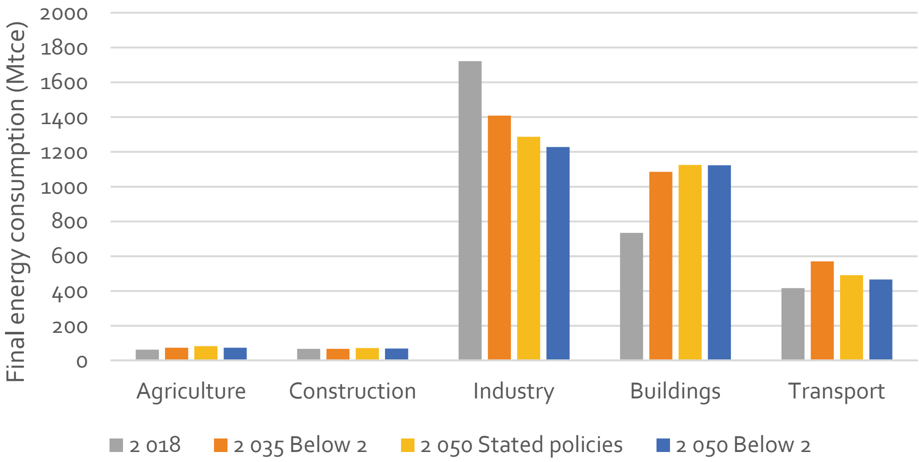
Figure 5-1: Final energy consumption by carrier in 2035 and 2050 compared with 2018 (Mtce)



The energy transition is thereby able to support the targeted economic expansion with similar levels final energy consumption, through a process of emphasis in the economic structure, improvements in energy efficiency of devices and production measures, as well as shifting away from direct use and combustion of fossil-fuels, towards consumption of electricity.

Along with the inter and inner structural changes, China will continue its economic growth while driving down its energy demand to a more balanced structure. The future energy growth will be centred on transportation and building sectors (both residential and commercial). By 2050, the final energy demand shares in industry, transportation and building sectors will change from the current 54%:14%:25% to 44%:18%:34% in 2035 and then to 41%:26%:38% in 2050. The stable decline of industrial energy consumption benefits from this on-going industrial upgrade, which reins in the current energy-intensive and polluting activities and thoroughly boosts the energy efficiency. A wide-spread electrification of transport offsets the incremental energy demand brought by car ownership growth and keeps it within a small range. A strong demand growth in the buildings sector is excepted due to continuing economic growth, urbanization and increasing attention to indoor comfort levels.

Figure 5-2: Energy consumption in end-use sectors (Mtce)



Energy efficiency improvement is a crucial step of the energy transition. By improving the energy efficiency of the economy as it expands, the rapid acceleration of clean energy supply can displace fossil energy consumption and not just satisfy new demand.

Electricity is decarbonised through expansion of non-fossil electricity sources

By 2035, the Stated Policies scenario sees more than a doubling of the non-fossil share of electricity supply from about 31% in 2018 to 64%. The Below 2 °C scenario goes even further, achieving 78% non-fossil supply by 2035. By 2050, the non-fossil electricity supply is 86% in the Stated Policies scenario and 91% in the Below 2 °C scenario. Both development pathways presuppose firm implementation of key policies including the ongoing power market reform ensuring a competitive level playing field for renewable electricity. This involves fossil-fuels bearing an increasing proportion of the societal costs of their emissions e.g. through further development of the emissions trading system which is being deployed.

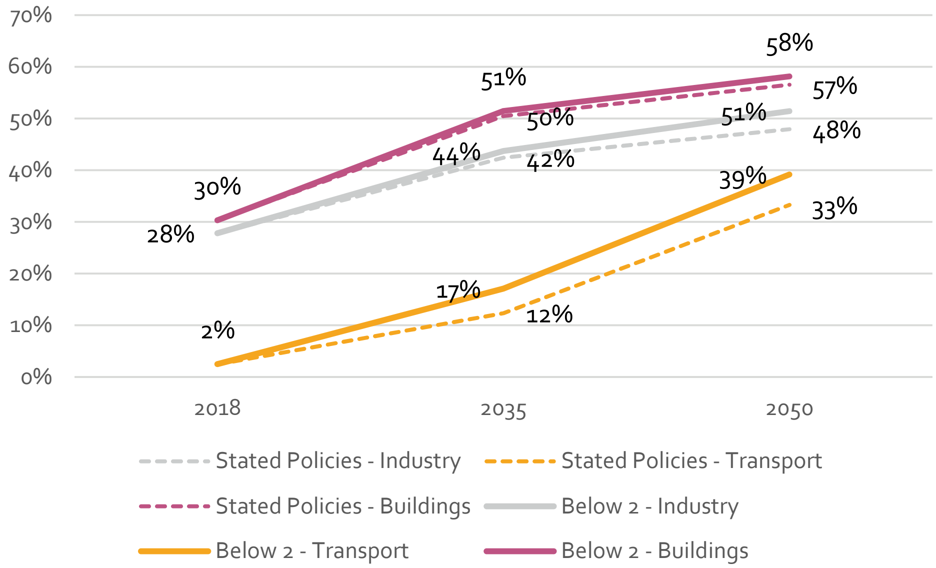
Electricity from wind and solar account for the lion's share of this transition, with 42% of the electricity supply coming from wind and solar by 2035 in the Stated Policies scenario. This development is enhanced in the Below 2 °C scenario as 58% of the total electricity generation comes from wind and solar in 2035. By 2050, wind and solar electricity account for 63% and 73% in the Stated Policies and Below 2 °C scenarios, respectively.

Electrification enhances the reach of decarbonised electricity supply

The IEA states in World Energy Outlook 2018[212] that "*A doubling of electricity demand in developing economies, puts cleaner, universally available and affordable electricity at the centre of strategies for economic development and emissions reductions.*" Due to the cost-reductions in renewable electricity supply sources, electricity becomes an increasingly cost-competitive energy carrier and thereby a means to replace direct consumption of fossil fuels.

The electrification rate increases from approximately 26% in 2018 to 43% in the Stated Policies scenario and 48% in Below 2 °C scenario by 2035[213]. Electrification expands further to 54% by 2050 in the Stated Policies scenario and 66% in the Below 2 °C scenario.

Figure 5-3: Development of electrification in transport, industry and buildings



By 2050, transport sector has reached 39% electrification in the Below 2 °C scenario, from 2% in 2018. Industry has increased from 28% to 51% and buildings from 30% to 58%.

The heating system and the central role of district heating

Heating system reforms in China deserve particular attention due to the expected large energy consumption. Heat consumption is expected to grow from around 4,500 TWh/year in 2020 to around 5,900 TWh in 2050 for buildings. After 2035, the consumption will stabilize. The increase will be largest in rural areas despite urbanization and increasing space area demand per inhabitant.

With a supply of around 2,300 TWh, district heating is responsible for around 50% of the all heating demand in 2020, decreasing to around 45% in 2050 for Stated Policies and 47% for Below 2 °C scenario. In the Below 2 °C scenario, new technologies develop more than in the Stated Policies scenario, with more electric boilers, heat pumps and heat storage capacity. The declining capacity in Stated Policies scenario and the stable capacity in Below 2 °C scenario both cover an increased efficiency in production and supply of district delivering most in Below 2 °C scenario. Space heating supply delivers the main energy conservation in the building sector, through district heating and better-insulated buildings.

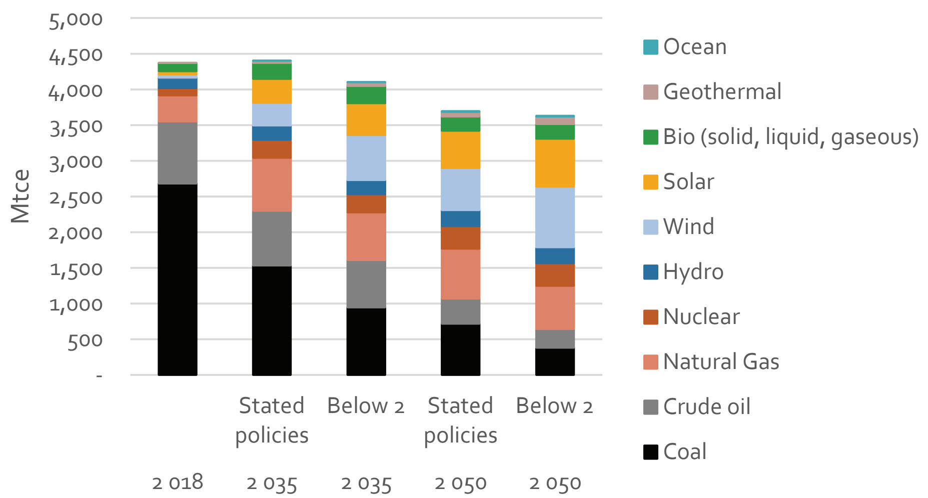
Other secondary energy carriers are deployed enabling further reach of decarbonised power

Particularly, in the Below 2 °C scenario, the transition is pushed further to include other secondary energy carriers like hydrogen. Hydrogen offers feasible ways to better intake renewable electricity and decarbonise a range of sectors – including long-haul transport (as fuel), chemicals (as feedstock), and iron and steel (as reductant to replace coke). The share of hydrogen in the final energy consumption reaches 2.3% in 2035 and 4.5% in 2050 in the Below 2 °C scenario, consuming 1,047 TWh and 1,536 TWh more electricity respectively.

Primary energy consumption mix is diversified as low-carbon sources replace coal

By 2035, coal's contribution towards primary energy consumption has been reduced by 51% in the Stated Policies and 62% in the Below 2 °C scenario. By 2050, the Stated Policies scenarios coal consumption is reduced further to 73% of the 2018 level, while the Below 2 °C scenario is reduced by 82% in total. Thereby coal, which accounted for approximately 61% of the primary energy supply in 2018, is reduced to account for 30%/23% in the Stated Policies and Below 2 °C scenarios respectively in 2035 and 16%/11% respectively for the scenarios in 2050. These shares are calculated based on the physical energy content method.

Figure 5-4: Primary energy consumption in 2035 and 2050 compared with 2018 (Mtce)



The share of non-fossil energy in primary energy consumption expands

Using the physical energy content method, the non-fossil energy consumption share expands to 32% by 2035 in the Stated Policies scenario and 42% in the Below 2 °C scenario. By the coal substitution method of primary energy accounting, commonly used in Chinese energy statistics and policy targets, the non-fossil energy proportion becomes 47% and 59% in the two scenarios respectively for the same year. Thus by 2035, the non-fossil energy proportion would far exceed the official policy target of 20% by 2030. It is apparent, that the 2030 target needs to be increased and there are strong indications that this is understood by the GoC.

Natural gas' contribution to primary energy expands considerably

In the Stated Policies scenario, natural gas accounts for 20% of primary energy by 2035 and 21% by 2050. In the Below 2 °C scenario, the natural gas consumption share is 18% in 2035 and 16% in 2050. This marks a temporary increase and then decrease in shares from 2018, which were 8%. In this context, natural gas can act as a temporary intermediary solution for coal substitution to serve the purpose of short-term emissions reduction.

5.2 Developing a clean, low-carbon, safe and efficient energy system

The energy transitions outlined in the scenarios, shed light on what is needed for the transition of the Chinese energy system to be successful. Both scenarios take giant strides towards achieving these objectives, but the analyses show that the Below 2 °C scenario has superior performance.

Emphasis should be on the Below 2 °C scenario for a Low Carbon Energy system compliant with Paris objective

Achieving the GoCs ambitions for a low carbon energy system requires fast and firm implementations policy measures to peak CO2 emissions in time. China's contribution is essential for global efforts to comply with the temperature objectives of the Paris agreement. The Below 2 °C scenario's approximately 195 billion tons of accumulated CO2-emissions is a pathway for China, which significantly and responsibly contributes towards this success of the global effort. The Stated Policies cumulative CO2 emissions must also be characterised as an impressive and massive transformation of China's energy system, and compliance with current targets and policy objectives, but is likely to be insufficient towards adequately curtailing the global temperature increase.

Figure 5-5: CO_2 emissions from fossil-fuels in the two scenarios (million ton/year)

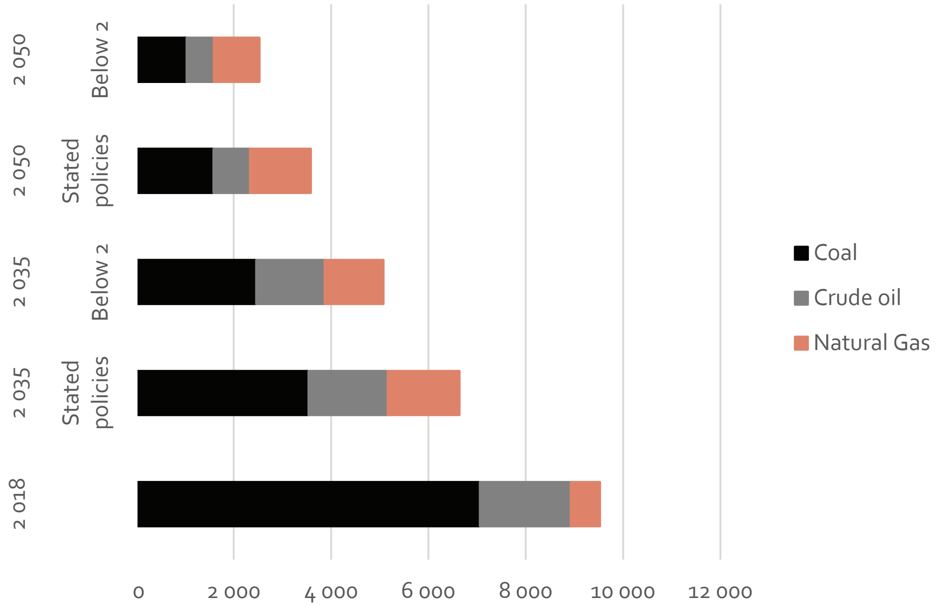
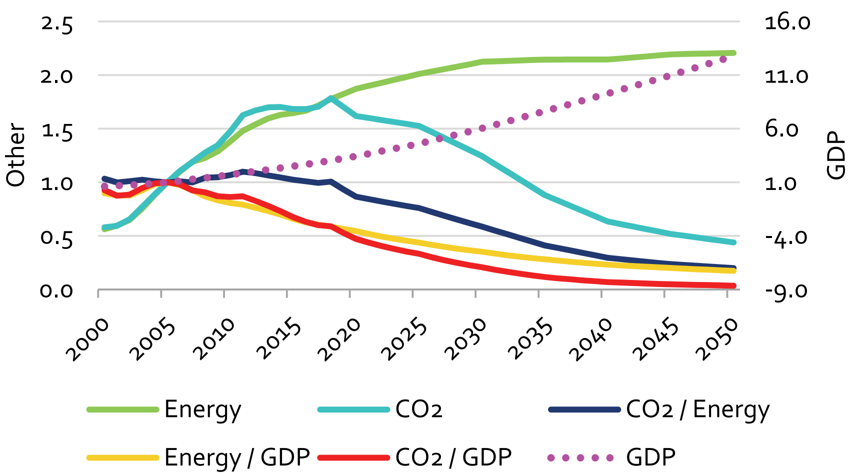


Figure 5-6: Development of Energy, CO_2 and GDP and their relationships (index=2005)

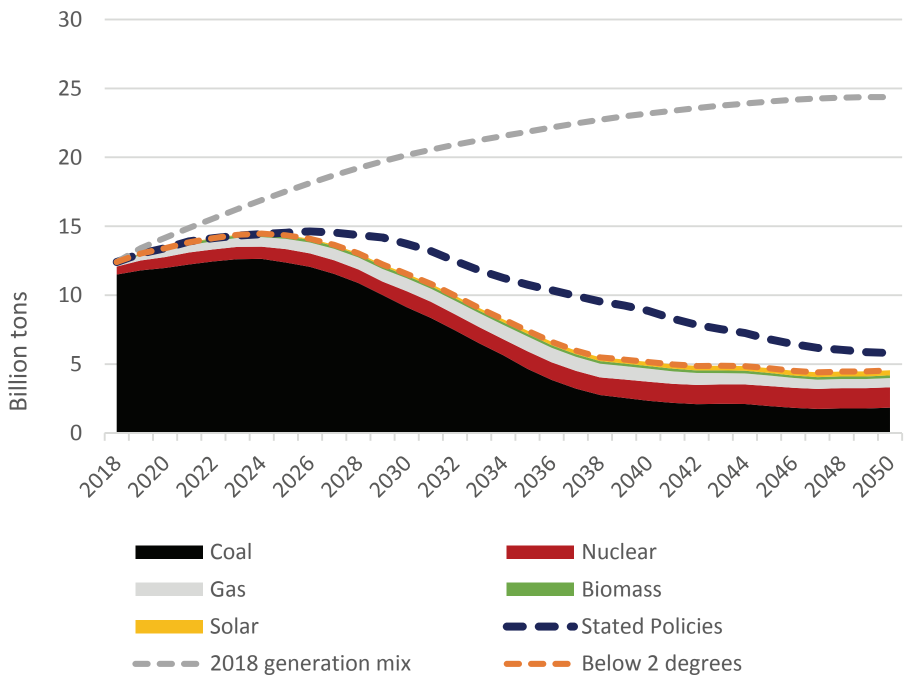


Clean Energy Transition contributes to addressing China's water stress

In both CREO scenarios, total water consumption for power generation falls despite the expansion of power generation. This is primarily due to a shift away from coal-fired power generation. Figure 5-6 shows how the energy transition is important in achieving this, by comparing the water consumption which would arise from a continuation according to the current generation mix with the scenarios. Next to coal, nuclear-based electricity generation accounts for the largest share of water consumption for power generation.

By 2035, the Below 2 °C scenario's water consumption from power generation has dropped to 7.4 billion tons p.a. from approximately 11.6 billion tons in 2018. By 2050, this is further reduced to 4.6 billion tons, with about half attributable to nuclear power.

Figure 5-7: Water consumption from the power generation the two scenarios, as well as a hypothetical situation where the generation mix from 2018 is frozen through to 2050

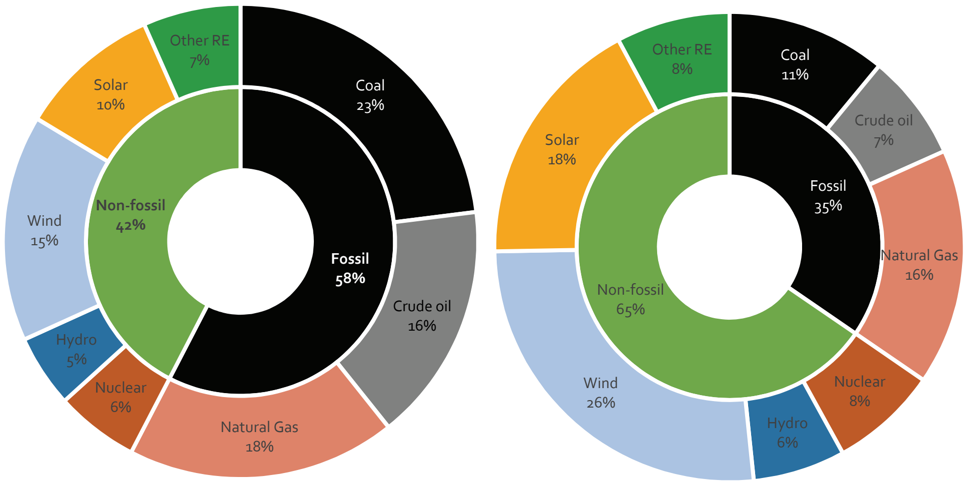


Note: The results depend on underlying assumptions for water intensity, with the figures displaying the medium estimates.

The overall energy system in 2035 and 2050 is more diversified

The share of coal in the total energy consumption is reduced from about 61% in 2018 to 23% 2035 and further to 11% in 2050 in the Below 2 °C scenario. By 2035, oil and gas each account for 16-18%, while non-fossil sources contribute with 42% in the Below 2 °C scenario (32% in the Stated Policies). By 2050, wind accounts for 26% and solar accounts for 18% of total primary energy in the Below 2 °C scenario.

Figure 5-8: Primary energy mix after two coming eras of transformation (Below 2°C)



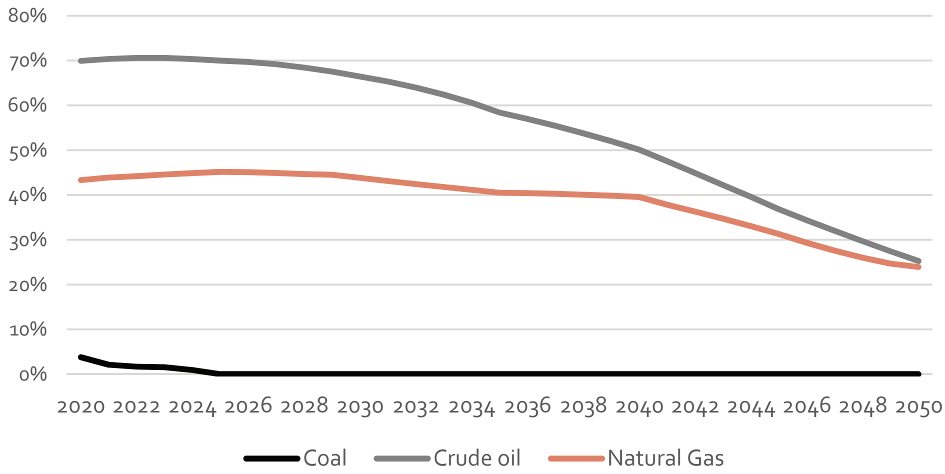
2035 – 4025 mtce (sec) ***2050 – 3536 mtce (sec)***

Energy security improved in both scenarios, but more in the Below 2 °C scenario

In 2018, China depended on energy imports for 21% of energy supply. Oil imports account for almost 71% of national oil consumption and about 45% of natural gas was imported. The share of energy imports in the total energy consumption is reduced to 14% 2035 and further to 5% in 2050 in the Below 2 °C scenario.

The aspect of improved energy security in both scenarios, but the Below 2 °C scenario in particular, is the shift away from oil consumption in the transport sector as the transport sector is electrified. Oil consumption declines from 941 mtce (608 mtoe) in 2018 to 259 mtce (181 mtoe) in 2050.

Figure 5-9: Import shares of fossil fuels in the Below 2 °C scenario



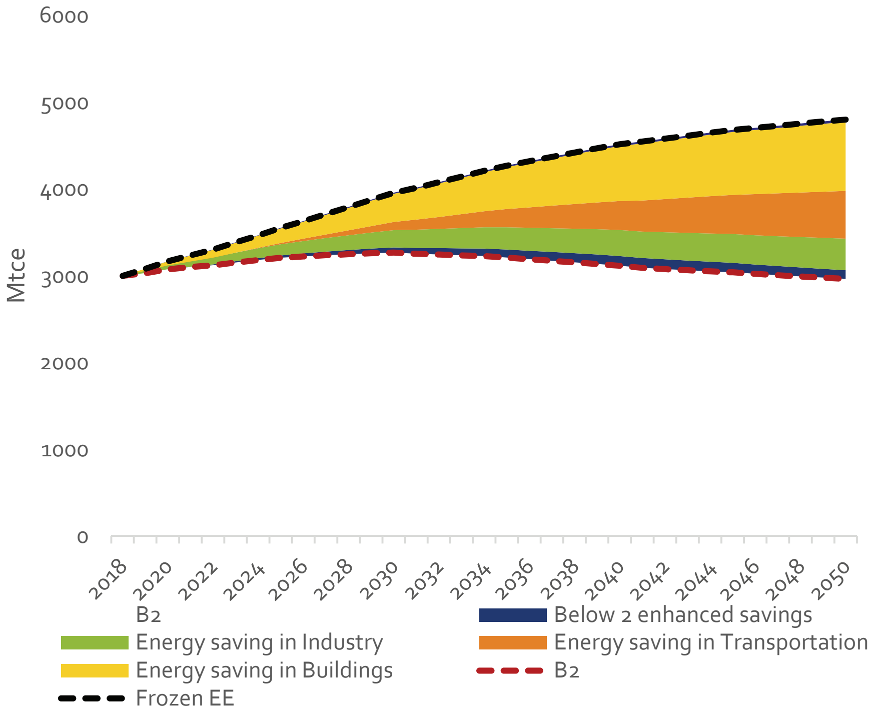
The presumption in the scenarios, that the share of natural gas will increase, creates new import sensitivity for China's energy system. In the Below 2 °C scenario, natural gas import rise is contained from 123 bcm in 2018 to 224 billion m^3 in 2035 and 104 billion m^3 in 2050. While, the exposure to gas import dependency rises in the medium-term in both scenarios, it is higher in the Stated Policies scenario (326 billion m^3), due to more gas use in both the end-use sectors and the power sector.

Power system reliability is a key prerequisite for a safe energy system

In the scenario analyses, the system's ability to handle fluctuations in load and production from wind and solar are evaluated in the power dispatch model, and the necessary measures to ensure a reliable power system are introduced in form of flexible power plants, energy storage, flexible use of the transmission system, and demand response (DR) measures, such as intelligent charging of electric vehicles (EVs). See more about this in the Power Sector Outlook.

Efficient energy system

Figure 5-10: Energy saving realised by efficiency improvement in the Below 2 °C scenario



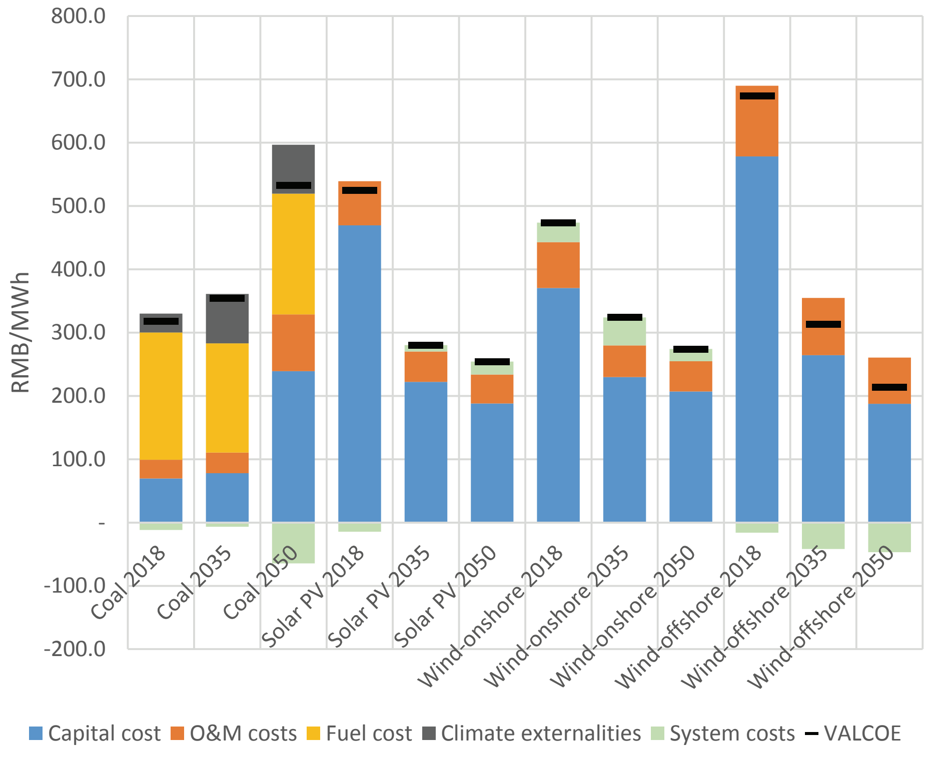
Both the Stated Policies and the Below 2° C scenarios utilise wide energy efficiency policies. For most sectors, the technology shift from fossil fuels towards renewables does not decrease energy demand, putting a strain on the needed transition. In efforts to reduce end-use energy demand, direct energy efficiency improvement and indirect energy efficiency improvements are utilised. The direct energy efficiency improvement, including more efficient consumer products, process efficiency gains in industries and especially improved insulation in the building stock, serves in both scenarios to limit the needed investments in added capacity. Indirect efficiency improvements, such as raising vehicle efficiency by adopting electric vehicles, has a larger benefit in the Below 2° C scenario. The indirect efficiency improvements at end-use consumption, largely connected to electrification, only has benefit for the overall system if the upstream transformation and energy production is efficient and clean. Electrifying before the power sector has made a sufficiently green transition can thereby backfire which is reflected in the Stated Policies scenario as it benefits less from electrification relative to the Below 2° C scenario.

Cost of wind and solar are a key driver of a financially viable energy transition, but successful system integration is key

The primary driver for this massive expansion of wind and solar is the cost-competitiveness of their electricity supply. While wind and solar today for the most part is still slightly more expensive than coal power, the pace of cost reductions is on track to end this. Wind and solar will be on par with coal during the 14th FYP period and drop below hereafter. This is fundamentally important for the planning of the energy transition, as the combined political aspirations of decarbonisation, clean air policy and future fossil fuel independency depends on it.

The competitiveness of new coal power is reduced significantly in the medium and long-term. The role of coal power changes from providing baseload electricity supply, to providing support for the power system as the renewable penetration share is increased.

Figure 5-11: Levelized cost of electricity from new coal, wind and solar (USPV) including value adjustments (system costs) and average operating hours from the Stated Policies scenario



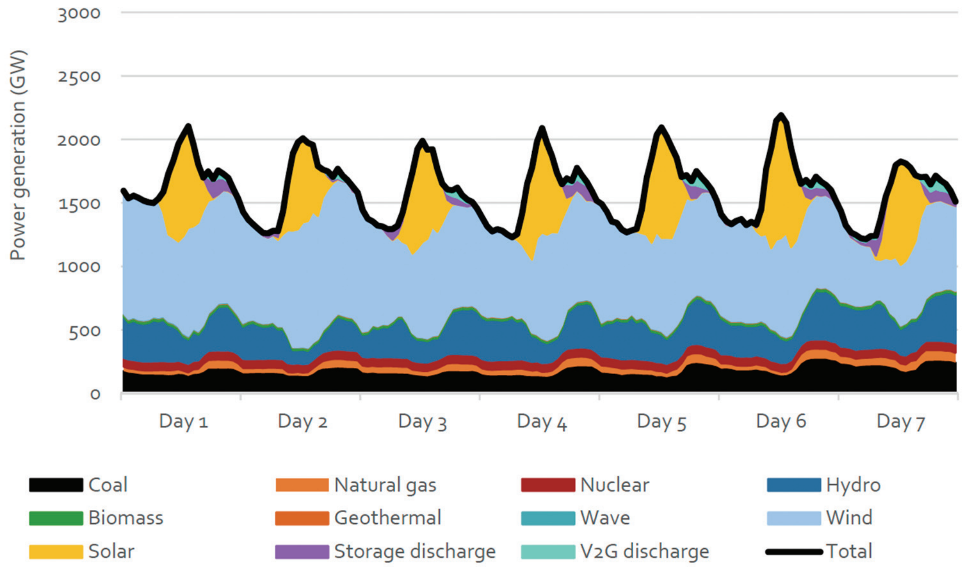
Note: For 2018 average full-load hours for the technology is used in the calculations, which for 2035 and 2050 the average FLHs for the respective technologies in the Stated Policies scenario is used. The system costs reflect the difference between the specific technology's average system value of generation and the average over all technologies in the Stated Policies scenario for that year. In a market setting, this *reflects the higher (or lower) energy price that can be captured by the technology vis-à-vis the average. Two key factors determine this for the technologies averaged over all of China, namely the timing and location of generation vs. the needs in the system.*

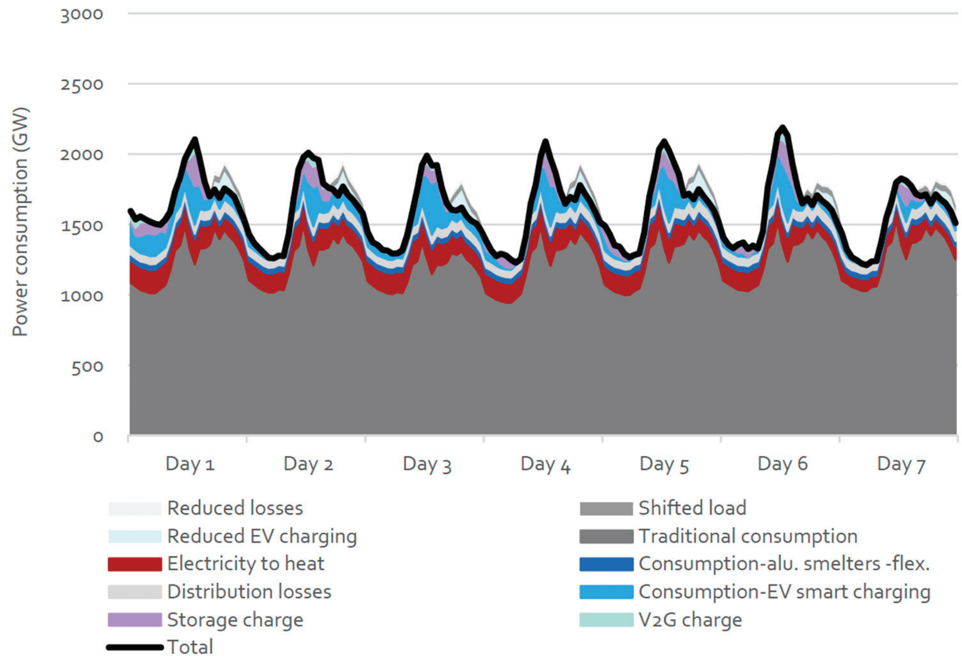
The LCOE concept makes costs comparable per MWh between technologies, yet in an energy system context, and the capacity factor (or full-load hours), a key input to the LCOE calculation, is determined by competitiveness according to short-run marginal costs. While the LCOE of coal power is not expected to increase significantly on an equal running hour basis, despite the added cost of CO_2 emissions under the ETS, the annual operating hours increasing the fixed cost contribution on a per MWh basis. The premium value of dispatchability will only partly compensate this to a lesser degree.

Cost efficient system integration is a central challenge of energy transition

Variable renewable electricity provides the lowest cost of electricity and constitutes one of the lowest cost options for displacing other fossil energy consumption at utility-scale. The transition is made cost-efficient in the scenarios by utilising all available cost-effective sources. This includes a host of technical messages in both power generation-side and consumption-side. Various flexible sources, including storage, V2G, industrial load shifting, and smart EV charging are mobilized to accommodate the power system fluctuation caused by high share of VREs. The system will include new technologies as well as retrofitting and designing thermal plants for flexible operation, using the flexibility of hydro reservoirs, expanding and utilising the power transmission grid efficiently.

Figure 5-12: Power generation and consumption profile in China in 2050 winter (Below 2 °C scenario)





These are motivated and coordinated through efficient merit order dispatch accounting for marginal CO_2 abatement costs and externalities, driven by dynamic pricing in well-functioning spot markets.

Energy system transition is affordable and cost efficient but requires more upfront investment and a new approach to institutions, regulations and management.

Part3:
Energy Sector Development Roadmaps

6. Industry development roadmap

6.1. Main findings

The final energy consumption in industry shall decline due to improvements in energy efficiency and structural changes in the industrial output. In the Stated Policies scenario, the final energy consumption decreases by 25%, from 1720 Mtce in 2018 to 1290 Mtce in 2050, further to 1230 Mtce in the Below 2 °C scenario, meaning a 29% reduction.

The fuel mix shall be cleaner. Coal consumption shrinks dramatically, from 53% in 2018 to 14% in 2050 in the Stated policies scenario and to 10% in the Below 2 °C scenario. Electricity as a share of final consumption increases from 23% to 49% in the Stated Policies scenario and to 51% in the Below 2 °C scenario. The process of electrification plays a role in modernising industries and increases long-term competitiveness. Industrial electrification benefits from the availability of low-cost decarbonised electricity, while modern industrial processes can supply flexibility for the power system.

Energy savings are a main driver for future energy consumption control. Industrial energy saving potential is about 364 Mtce in the Stated Policies scenario, and 424 Mtce the Below 2 °C scenario. Energy savings are a collective effect of innovative technologies replacement, fuel change caused by appliance shifting, and single technology improvement. Among them, technology replacement shows the largest potential, about 207 Mtce; from the sectoral perspective. Iron and steel industry has the most significant potential, about 231 Mtce, but with the condition that 65% of steel shall come from recycled scrap by 2050.

Useful energy analysis for energy services indicates process heating will be the most electrified end-use in industry. Under the Below 2 °C scenario, 129 Mtce more electricity will be put into use of process heating by electric heat pumps, electric boilers, induction furnaces, microwave sintering etc. Additionally, 132 Mtce of electricity will be used to produce electro-chemicals like hydrogen.

Industrial CO_2 emissions show steady decline. Renewable energy and energy efficiency provide the optimal pathway to deliver most of the emission reductions needed at the necessary speed. These two factors reduce the yearly energy related CO_2 emission in industry from the current 2854 million tonnes to 977 million tonnes by 2050, and the deepened measures in Below 2 °C scenario can provide further reductions in CO_2 emissions by as much as 24% to 736 million tonnes in 2050.

The future work priorities and phased objectives should be centred on energy saving and decarbonisation. Detailed movement and sectoral targets can be found in the strategic roadmap in the end of this chapter.

6.2. Current situation, requirements and transformative trends

China has undergone rapid industrialization, achieving one of the world's highest industrial growth rates. Total industrial added value was up to 36,000 billion yuan in 2018 from 175.5

billion yuan in 1978, with average annual growth of around 14.2%. Industry has been a major factor contributing to China's rapid economic rise and a cornerstone of the economy.

From an ecological perspective, China's industrial growth has created a major source of pollution, energy consumption, greenhouse gas emissions and waste generation, which impose significant costs on the economy and have an increasingly adverse impact on health and the environment. According to the China Energy Statistical Yearbook, in 2016 China's industrial sector consumed 2.1 billion tce, accounting for 59% of the total final energy consumption. From 1995 to 2015, the CO_2 emissions of China's manufacturing industry increased by approximately 221% and accounted for 58.3% of national CO_2 emissions[214].

With the increasing concern of the environment, economic growth is not the only driving force for industrial development. New requirements rise to promote the transformation of industry and balance economic, social and environmental sustainability factors. The future changes in industry lie in *industry restructuring*, *deep decarbonisation and fuel switching*, and *energy efficiency improvements*.

Industry restructuring

Since 2000, capacity expansion in several industries in China, such as steel, cement, aluminium, has become increasingly disconnected from market demand. Actions to curb this have been constrained because regions with the most acute challenges of overcapacity lack incentives to address them. However, as China's industrialization process deepens, energy-intensive branches will nevertheless reduce their excess production capacity according to the market trends, tempered profitability and strengthened polices.

Previously, China's industrial competitiveness relied on abundant cheap labour and the low pricing on environmental externalities. As labour and other business costs increase, the era of low-end manufacturing is coming to an end. An industrial upgrading is now required in China in order to become more environmentally sustainable. Policies, such as *Made in China 2025*, have promoted a shift towards higher value-added production through domestic innovation and industrial upgrading. In the future, urban industries such as food manufacturing and textiles will continue to increase; service-oriented manufacturing and producer service industry which featured with low-energy-intensity and high-added-value will be scaled-up.

Deep decarbonisation and fuel switching

China's industrial energy consumption relies heavily on fossil fuels, especially coal. In 2016, coal and coal products assumed approximately 56% in industrial final energy consumption, while electricity only took up to 23%. In the EU, the share of coal and coal products in industrial final energy use is about 13%, while the share of electricity is about 32%.

In order to develop an effective strategy for future decarbonisation, a deep understanding of the end-use of coal in industry is needed. According to our analysis, the use for process heat and process steam is almost 64% of the total coal and coal products consumption, of which the coal burned in cement furnace alone takes up to 20 percentage points; coal use in chemical industries as feedstock accounts for 12 percentage points; coke use as a reaction agent in steel production is about 24 percentage points. The heavy coal consumption is not only a result of the current industrial structure, but also a reason for the low industrial energy efficiency.

China needs to accelerate its coal phase-out process in industry. In the short term, a realistic choice is to promote natural gas as a main replacement for coal to provide process heat and steam. In the medium and long term, green electricity will become the main source for industrial energy supply.

- Electric heat pumps are expected to produce low temperature heat.
- Electro-magnetic heating technologies, which allow for more rapid and more controllable processing, will be used extensively in various industries for curing, gluing, laminating, melting, shrinking, soldering and tempering.
- Electric arc and plasma arc furnaces, ovens and kilns can replace their fossil-fuelled counterparts.

Innovative uses of hydrogen in industry would go along these developments, where direct electricity use is limited. Steel today is largely produced in blast furnaces and basic oxygen furnaces. Electrolytic hydrogen could replace coke in a large amount in direct iron reduction route, prior to smelting in electric arc furnaces together with scrap steel. Ammonia, methanol and a great variety of hydrocarbons can be produced from hydrogen and carbon, with benefits for the climate that differ according to the origin or that carbon, and the decarbonisation of electricity.

Energy efficiency improvement

Over the past decades, the Chinese government has launched a series of energy-efficiency directives for its energy-intensive industries which have had significant impact. During the period from 2005 to 2014, the energy efficiency of major energy-intensive products improved from 15% to 25%. However, compared to the post-industrial economies, China is still suffering low industrial efficiency. In 2016, China's overall industrial energy intensity per added value was almost two times higher than European countries. A higher degree of the efficiency potential needs to be realised.

The industrial structural adjustments and fuel shifting through appliance and technology replacement could be considered as a substantial part of energy saving effort. Additionally, single equipment improvement and production process optimization will also affect the overall efficiency. Better designed electric motors and other end-use devices will be promoted in suitable areas; waste-heat recovery and heat integration technologies, as well as smart energy management and optimization control technologies, will be more and more put into practice.

Recycling is another measure which can improve industry energy efficiency.

- Producing plastic products from recycled plastics reduces energy requirements by 60-70%.
- Recycled aluminium is 92-95% more energy efficient than making new aluminium.
- Using recycled scrap to make steel could save 60-70% of energy demand in the traditional BF-BOF process.

In addition to energy efficiency, these measures improve resource utilisation and reduce pollution. Moreover, most recycling processes require electricity to provide high temperature for melting and regeneration, which in turn contributes to the overall electrification process.

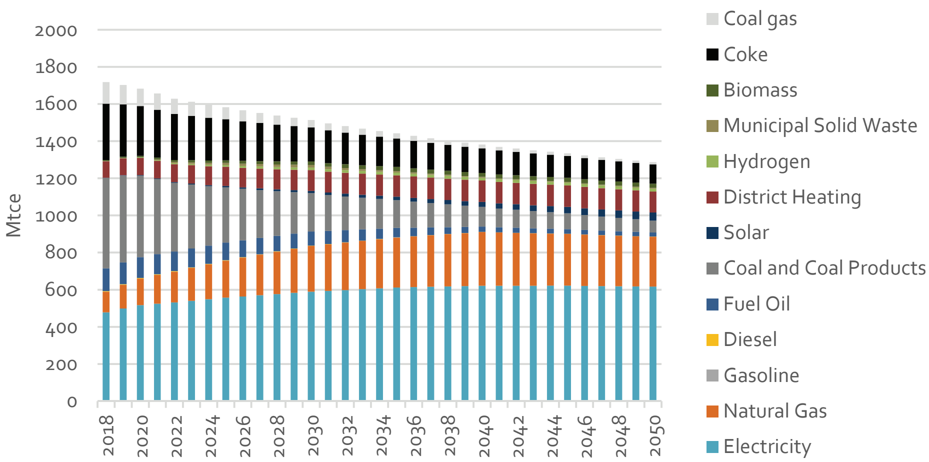
6.3. Future industry development

In order to reveal more details for the future development pathway, and shed light on the road mapping, CREO 2019 comprehensively simulated China's industrial energy use up to 2050 by the means of LEAP framework[215]. The key assumptions were set up according to the above development requirements, policy mandates, experts' judgement and the internal relation between industrial subsectors, etc. Additional tools, like the useful energy intensity analysis, were adopted to help revealing a detailed insight at the end-use level. Although cost is not a quantitative indicator in this model, it was still taken into consideration to make different development strategies in different scenarios.

Final energy demand in industry

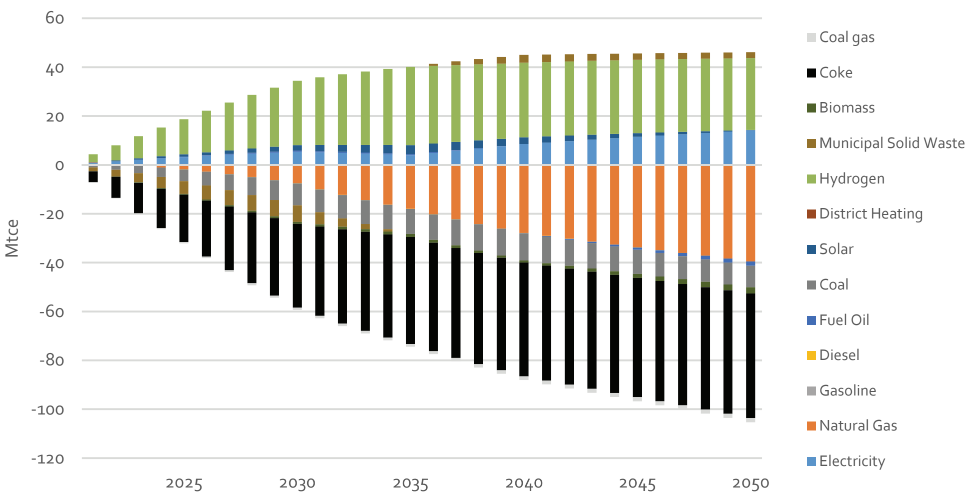
The Stated Policies scenario projects the overall industrial final energy demand in industry to shrink by 25% 2018-2050. The clean and renewable energy increases, while the hold of fossil fuel over the energy mix weakens, as seen in Figure 6-1. The total share of electricity and electricity-based hydrogen rises from 23% to 49%. Natural gas grows from 4% to 21%. District heating grows from 5% to 9%. Direct renewables together grow to 5%. Meanwhile, coal and coal products (including coke and coal gas) declines from 60% to 15% and oil products decline from 8% to 2%.

Figure 6-1: Industry final energy demand in Stated policy scenario (Mtce)



The effect of industrial reform and energy efficiency measures is even more significant in the Below 2 °C scenario, where additional 60 Mtce are saved by 2050 compared with the Stated Policies scenario. This change mainly comes from the replacing coal and coal products with electricity, natural gas and hydrogen. The use of direct renewables in consumption also increases. As Figure 6-2 shows, 44 Mtce of electricity, hydrogen and renewables could further replace 104 Mtce of fossil fuels in the Below 2 °C scenario.

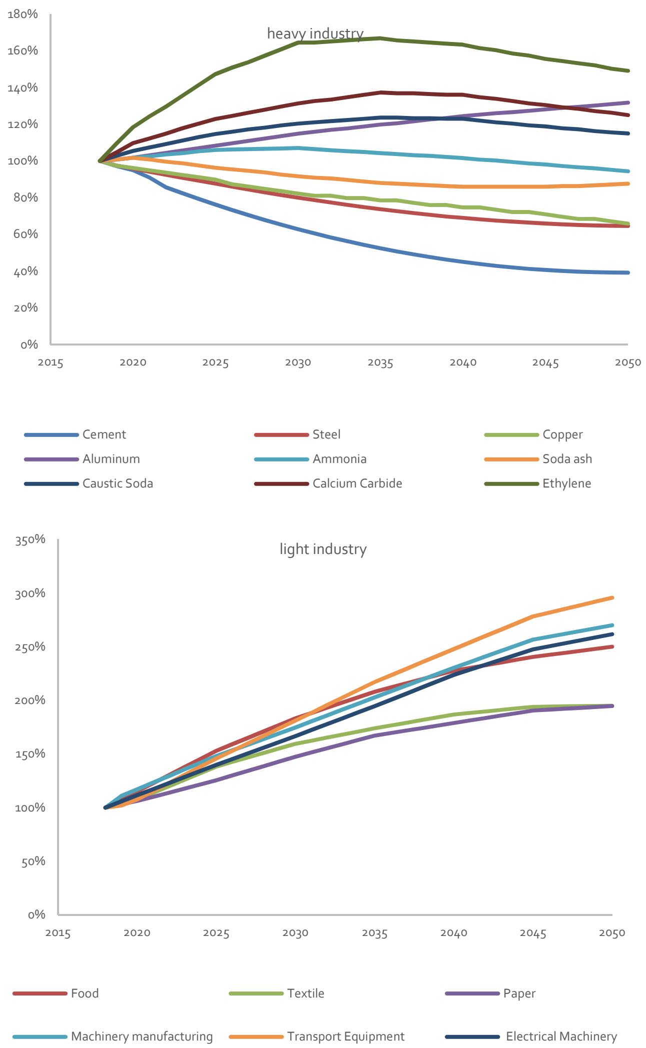
Figure 6-2: Industry final energy demand changes in Below 2 °C scenario (Mtce)



Sectoral energy demand rebalances by industrial restructuring

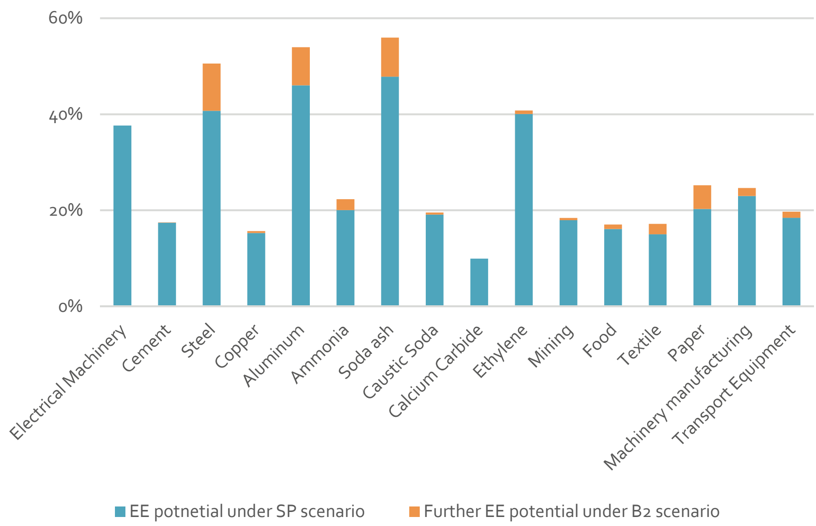
Struggling with excessive capacity and low profit levels for long time, most energy-intensive industries have already seen a peak in their market demand in China. In both scenarios, the demand of these energy-intensive products such as steel and cement are expected to decline sharply in the future (see Figure 6-3). By 2030, per capita consumption of energy-intensive products such as steel will reach the present average level of developed countries. By 2050, the production of steel will shrink by 35% compared with the current level, cement by 61%, and copper by 34%; while the output higher-end and more-value-added branches is expected to grow. The output of food industry, electric devices, machinery manufacturing and transport equipment is predicted to grow by 150-200% by 2050.

Figure 6-3: Output changes for different industrial branches



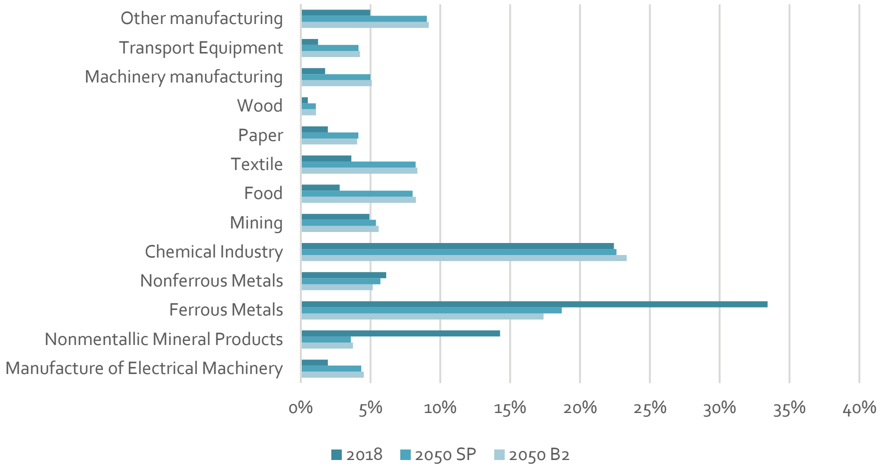
Meanwhile, with the reinforcement of resource and environmental constraints in the future, more low-end, inefficient, high energy-consuming and high-emission production technologies will be improved or substituted, which will further drive the decrease in future industrial energy intensity. The energy efficiency for different industrial branches will be improved to varying degrees, and in 2050, the energy intensity of heavy industry in China will be decreased at least to the current level of OECD and EU25. The results of the projections are shown in Figure 6-4. The highest energy efficiency improvement potential lies in steel-making, aluminium and soda ash industries, which almost reaches 50-60%. Due to the raw material availability or technological constrains, the potential for improving energy efficiency in the production of calcium carbide, cement, and copper industries is much smaller.

Figure 6-4: Energy efficiency improvement potentials for industrial products under two scenarios



Output changes and energy efficiency improvement together could result in a redistribution of industrial structural energy use share (see Figure 6-5).Today approximately 3/4 of consumption remains concentrated in 4 energy intensive branches, namely, chemicals, steel, non-metallic minerals and non-ferrous metals; moreover, the share of the above four energy-intensive branches will decline to 50% in 2050. Furthermore, a strong reduction for steel and non-metallic minerals consumption, 16% and 10% respectively, is expected. Chemicals will be the largest energy consumers in industry corresponding to about 23% for both scenarios in 2050), followed by steel which is 19% and 17% in Stated Policies and Below 2 °C scenario.

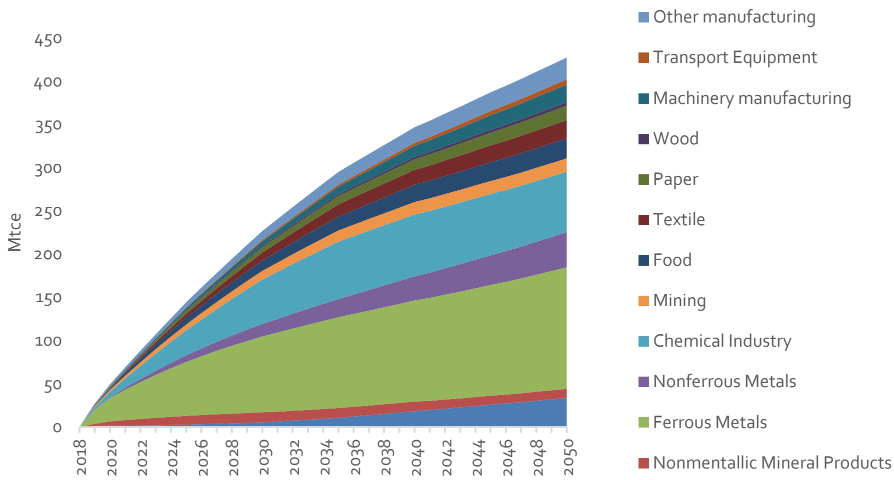
Figure 6-5: The share in the total energy demand



Energy savings potential for future industry

Industrial energy saving potential in the Stated Policies scenario is about 364 Mtce. From the sectoral perspective, iron and steel industry has the largest energy saving potential, about 231 Mtce, followed by chemical industry, about 78 Mtce. Nonferrous metals and food ranks third, about 40 Mtce.

Figure 6-6: Sectoral energy saving potential (Mtce)



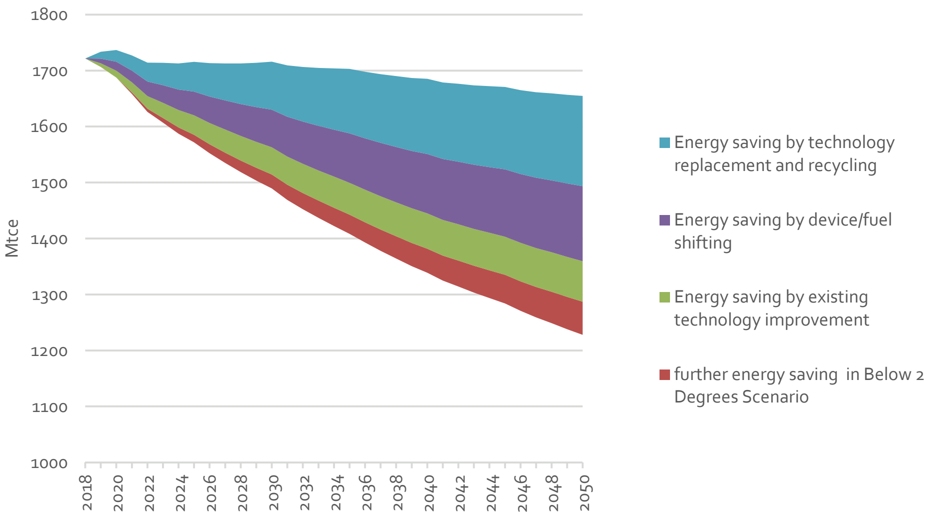
The industrial energy saving potential can be further broken down into three parts:

1. Energy saved by technology replacement
2. Energy saved by device shifting

3. Improvement of existing technology.

In the Below 2 °C scenario, most of the energy saving measures are taken a degree further and realise additional energy savings of 93 Mtce. Figure 6-7 shows that technology replacement contributes most to the energy saving, by which 59 Mtce energy could be saved in 2050, accounting almost 12% of today's industrial energy consumption.

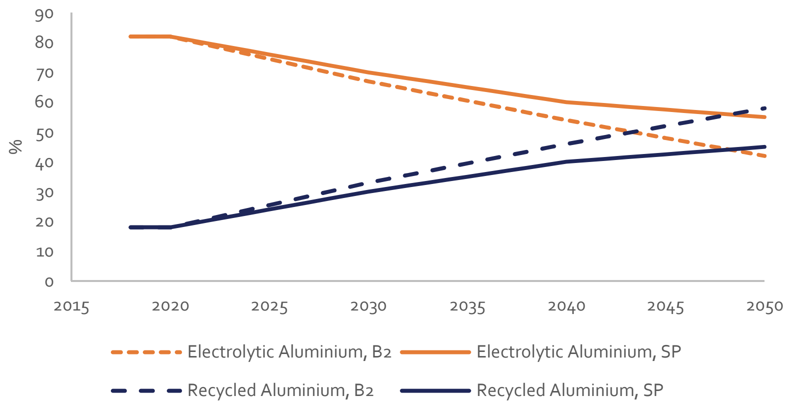
Figure 6-7: Industrial energy saving potential (Mtce)



Energy saved through technology replacement

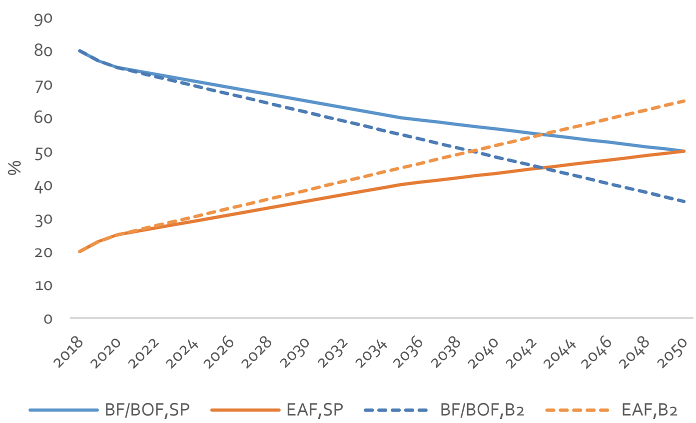
Resource recycling may be one major reason for technology replacement. By skipping the energy-intensive process to isolate the aluminium metal from bauxite, recovering aluminium from scrap to produce secondary aluminium ingot consumes about only 5-7% of the energy required to produce primary aluminium production technology. As shown in Figure 6-8, recycle rate rises from the current 18% to 45% in 2050 under the Stated Policies scenario, bringing 25 Mtce energy saving. In the Below 2 °C scenario, the recycling rate is further increased to 58%, saving an additional 10 Mtce energy.

Figure 6-8: Recycled aluminum shares under Stated policies and Below 2 °C scenarios



Using recyclable material such as ferrous scrap instead of iron ore, secondary steel avoids the massive coke consumption in pig-iron making in blast furnaces (BF) and could save more than 60% of the required energy. Furthermore, if economically convenient, new reducing reductant agent such as hydrogen may be introduced to further replace coke in the BF/BOF routine (blast furnace / basic oxygen furnace). Figure 6-9 shows the different assumption of Electric Arc Furnace (EAF) share under Stated Policies and Below 2 °C scenarios, respectively. By increasing scrap-based EAF steel share from the current 13% to 50% in the Stated Policies scenario, 60 Mtce could be saved. If this rate is further raised to 65% under the Below 2 °C scenario, another 35 Mtce could be saved.

Figure 6-9: EAF shares under Stated policies and Below 2 °C scenarios



Energy saved through device shifting

After structural reform and technology replacement, the shift of end-use device will further realise 134 Mtce of energy saving potential by 2050. For one same production technology, useful energy intensity will not change much in the future, but energy consumption for each end-use service will change according to the efficiency changes which are introduced by appliance shifting and efficiency improvement. From Figure 6-10, we can see that the largest energy saving is caused by the shift of process heating equipment. Appliance shifting not only boosts the energy efficiency, but also facilitates the transition from fossil fuels to clean energy.

Figure 6-10: Industrial energy demand in end-use level[216]

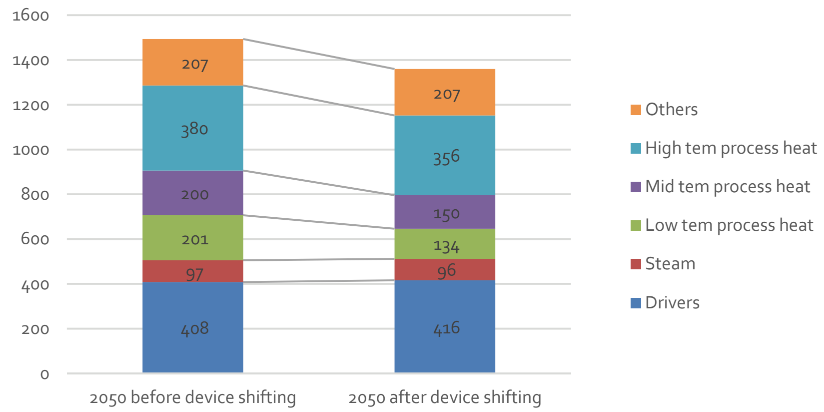
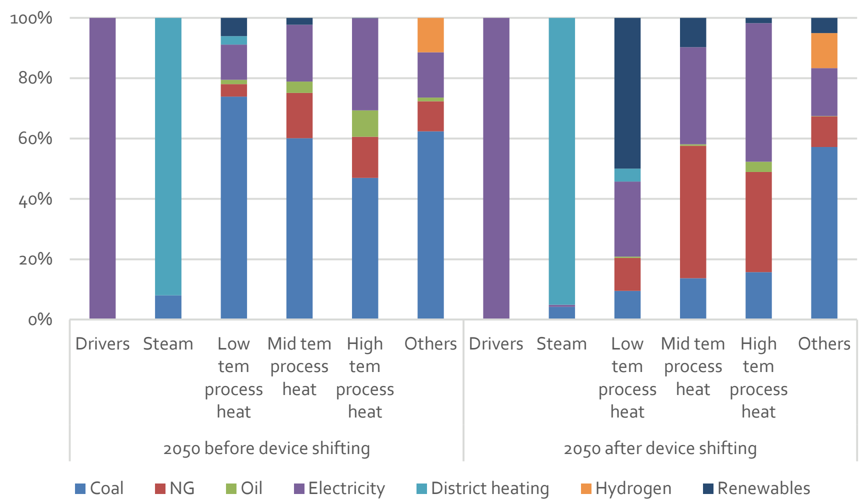


Figure 6-11 provides more detail about the appliance shifting. More low-temperature process heat will be provided by direct renewables and electricity: solar heaters, biomass boilers and electric heat pumps will replace the current coal boilers; for the medium-and high-temperature heat, natural gas boiler/furnaces and electricity-driven devices will replace the current coal boilers/furnaces.

Figure 6-11: Fuel mix in different end-uses before and after devices shifting



Energy saved through single technology efficiency improvement

Additionally, 72 Mtce could be saved through single technology efficiency improvements. The main change will happen in heating system. Heat consumption has especially been reduced by optimizing the facilities. For example, in a malt house, the gas boiler's efficiency could be increased from 90 % to 103 %, by establishing an exhaust gas heat exchange[217].

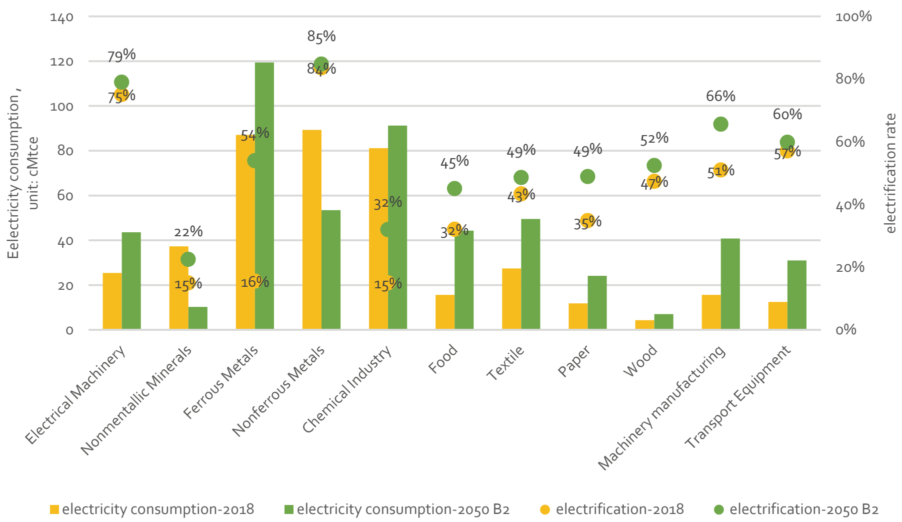
The role of electricity in future industry

Electrification in different industrial subsectors

There are large variations in the electricity consumption and electrification rate in different industrial subsectors, – in 2018, the total amount of electricity used in manufacturing industry[218] is around 490 Mtce, and the general electrification rate is about 25%. Of the current industrial electricity, 63% is used in the heavy industries, namely steel-making, chemicals, non-metallic minerals and nonferrous metals, but their average electrification rate is only 19%.

In the scenarios, the electrification rate of different manufacturing industries will rise in varying extent by 2050 (see Figure 6-12) and the general industrial electrification rate under the Below 2 °C scenario will eventually reach 51%. The most rapid electrification will happen in the subsectors: ferrous metals, non-ferrous metals, chemicals, machinery manufacturing, food and paper.

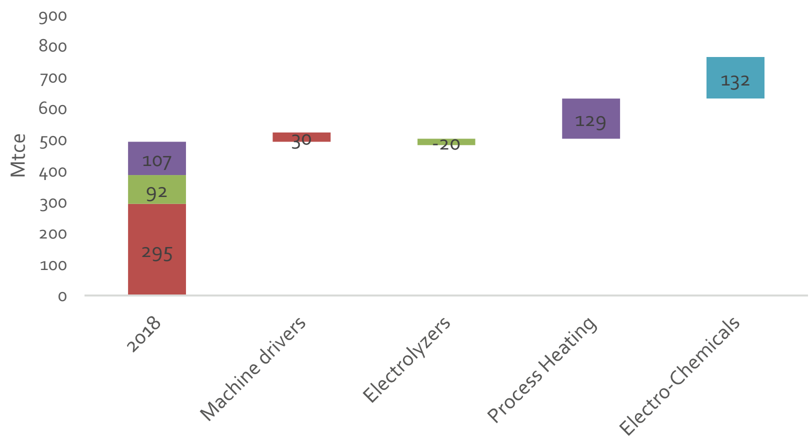
Figure 6-12: Share of electricity and electricity consumption in different sectors under two scenarios



Electrified end-uses by various technologies

Currently, within the electricity used in industry, 60 % is mainly to provide mechanical power for driving system, compressors and separation system, 19% for electrolysers, and 21% for process heating. However, the useful energy analysis shows that by 2050 the highest demand for end-uses is from process heating, accounting for 51% of the total useful energy use. This will be the most electrified form of end-use in industry. In the Below 2 °C scenario, 129 Mtce more electricity will be used for process heating by the electric heat pumps, electric boilers, induction furnaces, microwave sintering devices, etc. In addition to regular industrial electricity end-use, 132 Mtce electricity will be used to produce electro-chemicals like hydrogen.

Figure 6-13: Incremental electricity consumption in different end-uses in the Below 2 °C scenario



Flexible electricity consumption

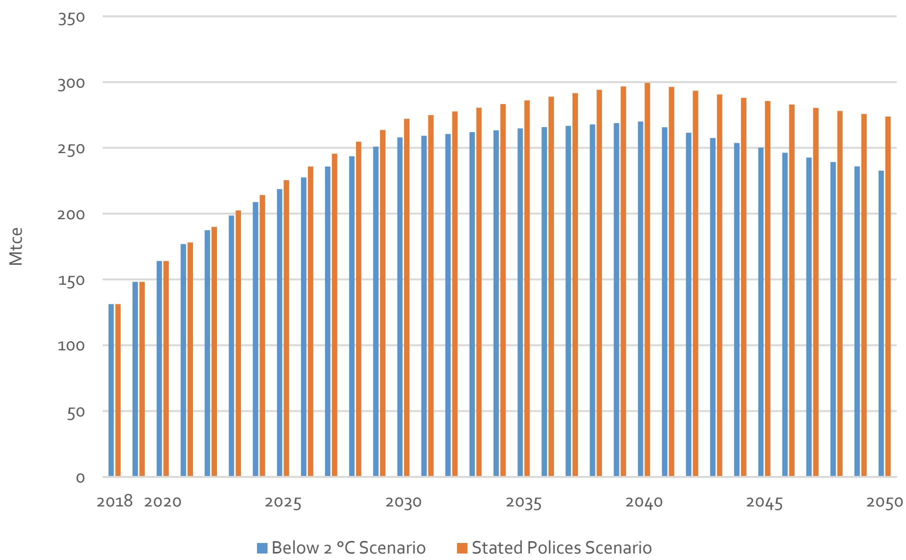
Currently, electricity consumption does not play a significant role in accommodating the different needs of power systems. Specifically, achieving a more flexible electricity generation which could compensate the variable generation from renewable energy sources has been the main focus. However, a more rational management of electricity demand could lead to significant benefits for power system while supporting the integration of variable renewable energy sources. Demand-side management (DSM) consists of unlocking the flexibility potential of electricity consumers' side, which change the demand according to the varying need of the system. With the increasing electrification rate, large potential of flexibility lies in the industrial sector. The aluminium sector, which consists of an electricity intensive sector, has been identified as a particularly good source of flexibility, where the original steady load curve can be altered within a certain range without compromising the operations. In Chapter 9, the flexibility potential of aluminium smelters is discussed in detail.

The use of natural gas in industry

Approximately 131 Mtce of natural gas was used directly by manufacturing industries in 2018. Hereof 77% was used for process heating (mostly for high temperature heat), and 20% as chemical feedstock. Natural gas is consumed primarily in the chemicals, petroleum refining, non-metallic mineral production, mining and quarry industries. These sectors account for over 72% of all industrial natural gas use in 2018.

Due to its significantly lower emissions coefficient relative to coal, natural gas is anticipated as an alternative fuel for coal in the short and medium terms. Natural gas shall be used more extensively in all industrial subsector in the future, especially for the medium and high temperature processing heat supply and as feedstock. Driven by forced policy target targets (e.g., Energy Supply and Demand Revolution (2016-2030)), the use of natural gas is expected to grow fast before 2030, and then reach the peak around 2040 under Stated Policies scenario; but such growth will be slowed down under Below 2 °C scenario considering its relatively high cost might hamper the price-sensitive industrial users.

Figure 6-14: Natural gas consumption in the two scenarios

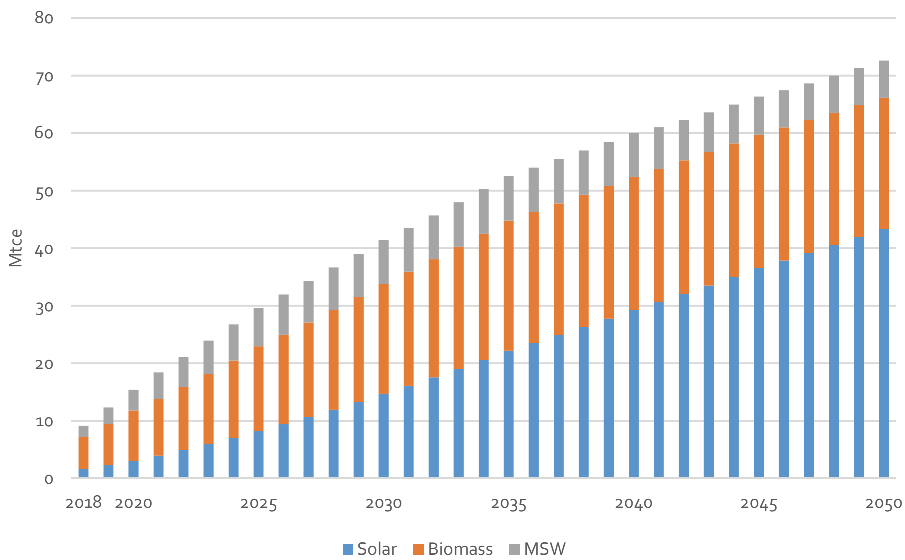


Renewable energy utilization

The uptake of renewables in industry will continue to increase steadily in all industrial subsectors, from the current 9 Mtce to 70-72 Mtce by 2050 in both scenarios. Solar thermal, wood-based biomass, municipal solid waste (MSW) will be the most used renewables in industry in the future.

- Solar thermal can fulfil a substantial amount of heat demand in industry, especially in food, textile and machinery manufacturing subsectors, for providing low temperature process heat. Heat in the lower temperature range (<80°C) can easily be provided with systems commercially available, such as flat plate collectors (FPC) and evacuated tube collectors (ETC). For medium temperature processes, new advanced collector designs have been successfully developed. Ultra-high vacuum FPC or ETC with concentrators can also generate temperatures of up to 200°C. Solar concentrators like parabolic dish collectors, parabolic trough collectors and Linear Fresnel collectors can generate compressed steam with temperatures of up to 400°C[219].
- Biomass will be increasingly applied for providing medium-temperature process heat in most of the industrial subsectors. Biomass boilers, biomass furnaces, biomass gasification furnaces, blending biomass during coke making to produce bio-coke should be further developed.
- MSW will continue to be used as co-firing fuel in kilns in cement production route. 9 million tons of MSW was burnt in cement kiln in China in 2017. Considering the composition and the average heating value of Chinese MSW, the future maximum co-firing rate in cement kiln combustion is set to 20%.

Figure 6-15: Industrial renewable energy consumption in the in Below 2 °C scenario



The role of hydrogen

Hydrogen offers feasible ways to expand the use of renewable electricity and displace fossil fuels in certain energy intensive industries.

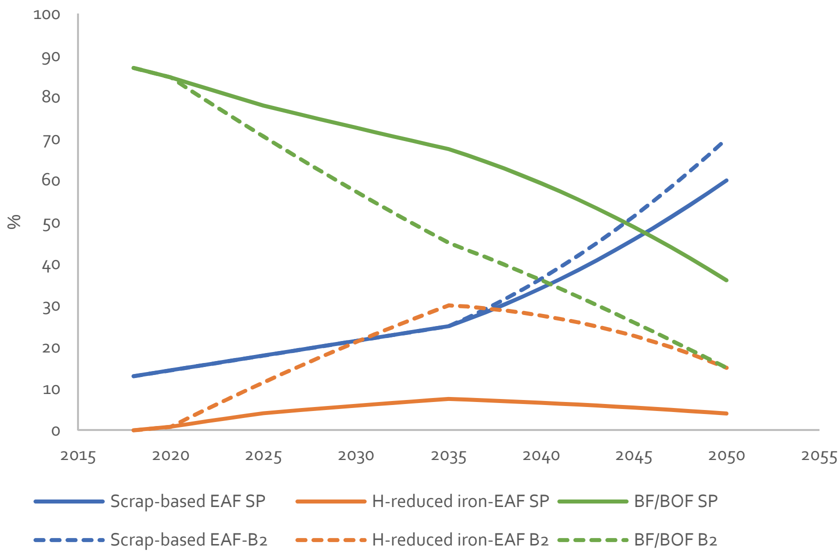
Hydrogen in steelmaking

Large amount of hydrogen will be used in in iron-making process as reductant to replace coke by two means:

1. Injecting hydrogen blended with coke-oven gas in the blast furnace to reduce the iron ore
2. Using pure hydrogen to reduce direct reduced iron (DRI) or sponge iron in fluidised bed reactors.

The reduced iron will then be sent to BOF or EAF for steel making. Figure 6-16 shows the trends of future technology share in the two scenarios. The share of hydrogen involved steel will peak around 2035, accounting 30% in Below 2 °C scenario and 8 % in Stated Polices scenario, and then drop to 15% and 4% respectively in the two scenarios, due to the development of steel recycling and scrap-based steel production.

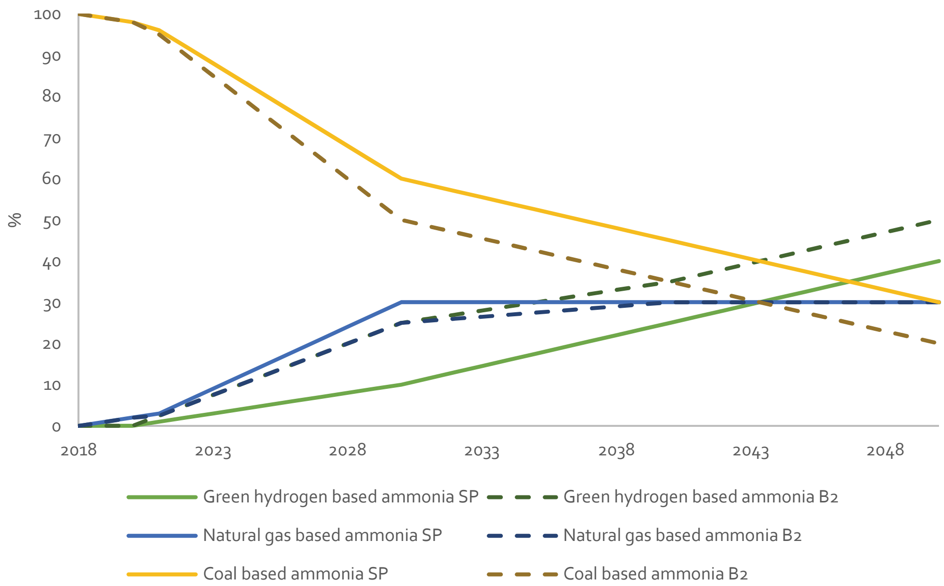
Figure 6-16: Different steel-making technologies' share in the two scenarios



Green ammonia

Ammonia industry also shows great potential to intake hydrogen. Currently, about 76% of ammonia in China is derived from coal, but with increasingly environmental pressures, coal-based feedstock will be gradually replaced by cleaner and less energy intensive energy like natural gas and electrolysis-based hydrogen. Figure 6-17 shows the trend. In the Stated Policies scenario, natural gas will exceed coal as the ammonia's feedstock by 2040, and the share of hydrogen-based ammonia will grow to 30% by 2050. In the Below 2 °C scenario, the share of hydrogen-based ammonia will exceed coal-based by 2030 and will finally grow to 50% by 2050. This could bring 12-14 Mtce energy saving.

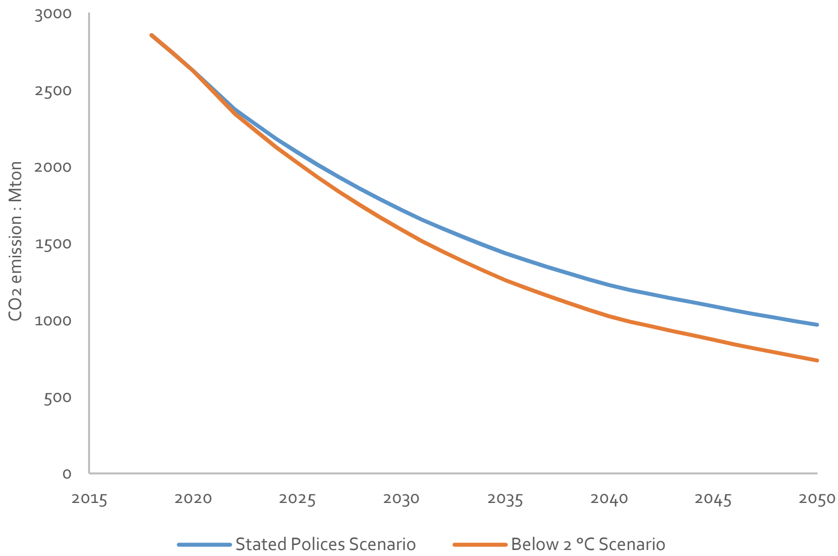
Figure 6-17: Different aluminum production technologies' share in two scenarios



Energy related CO_2 emissions from industry

Due to the electrification and decarbonisation process, the industrial energy-related CO_2 emission will be keeping dropping in two scenarios during the scenario period. And the combination all energy saving measures in Stated Polices scenario can help significantly reducing China's future industrial CO_2 emissions from the current 2854 million tonnes to 977 million tonnes by 2050, and the deepened measures in Below 2 °C scenario can help further reducing CO_2 emissions by as much as 24% to 736 million tonnes in 2050.

Figure 6-18: Industrial CO2 emission in the two scenarios

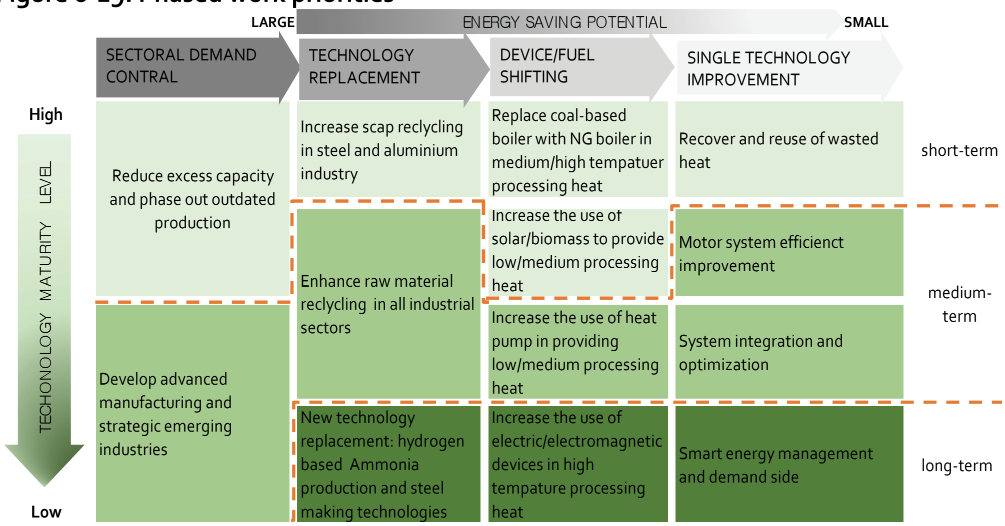


6.4. Industry development roadmap

Work priorities

The modelling results provide a clear picture of the future industrial energy consumption, from which energy savings and decarbonisation are the two cores aspects of future industrial development. The future work should be centred on these aspects, and the cleanest most efficient means should be prioritized. At the same time, technological maturity level and economic characteristics should be taken into consideration. Figure 6-19 show more details about the phased work priorities.

Figure 6-19: Phased work priorities



In the short-term, the priorities should be:

- Reducing industrial excess capacity
- Phasing-out outdated production
- Promoting the transformation and upgrading of traditional industries, while encouraging the collection of non-ferrous and ferrous scrap and increasing their recycling in steel and aluminium industries
- Replacing coal boiler with natural gas boiler in medium/high processing heat supply
- Increasing the utilization of renewables such as solar thermal and biomass in low/medium heat supply
- Making full use of waste heat

In the medium-term:

- The focus should be on accelerating the development of strategic emerging industries, as well as high-end equipment manufacturing which featured with low-energy-intensity and high-added-value.
- Enhancing recycling in all industrial sectors
- Increasing the use of electric heat pump to provide low/medium heat
- Improving motor systems' efficiency

In the long-term:

- Higher attention should be paid to commercializing innovative hydrogen-based technology.
- Increasing the use of electric/electromagnetic appliances in high temperature processing heat and promoting the adoption of smart energy management systems.

Overall objectives

The overall objectives for China's industrial sectors are to curb the total energy consumption while maintaining stable industrial economic growth, improve the energy mix and create space for the development of clean energy.

Short-term (14th Five-Year Plan period)

By the year of 2025, the total final energy consumption (TFEC) should be controlled within 1580 Mtce (91% of 2018's value); CO_2 emission within 2000 million ton (71% of 2018's value); electricity's share in the final energy consumption higher than 42%.

Medium -term (2025-2035)

By the year of 2035, the total final energy consumption (TFEC) should be controlled within 1400 Mtce (82% of 2018's value); CO_2 emission within 1260 million ton (44% of 2018's value); electricity's share in the final energy consumption higher than 51%.

Long -term (2035-2050)

By the year of 2050, the total final energy consumption (TFEC) should be controlled within 1300 Mtce (71% of 2018's value); CO_2 emission within 750 million ton (26% of 2018's value); electricity's share in the final energy consumption higher than 36%.

Sub-sectoral targets

Different targets are made for long-term decarbonisation and energy efficiency with the key industrial sectors, focusing on those that use the greatest amount of heat and represent the greatest greenhouse gas emissions.

Steel-making:

- Product output control: the annual crude steel production capacity should be controlled within 82 million tonnes by 2025, 69 million tonnes by 2035, 60 million tonnes by 2050 (Lightweight technology, Magnesium aluminium alloy will be used to replace steel in transport vehicle manufacturing)
- Energy intensity: general energy intensity for the whole steel-making industry should decrease 8-10% by 2025, 17-24%by 2030, 41-51% by 2050
- Resource recycling: the proportion of scrap-based electric arc furnace steel should reach 30-32% by 2025, 40-45% by 2035, 50-65% by 2050
- Supporting technologies: increase the energy efficiency standard and promote technologies such as Direct reduced iron production technology; Coal moisture control (CMC) Coke dry quenching technology; Sintering waste heat recovery and utilization technology; Low temperature sintering technology Mini-pelletized sinter process technology; BF top gas dry type TRT technology; Converter fume dry dusting technology; Converter flue gas waste heat recovery technology; Thin slab continuous casting technology; Energy management centre for steel enterprises;

Cement:

- Product output control: by infrastructure deceleration, also building quality improvement, cement production should be reduced to 1.6 billion tons by 2025; 1.1 billion by 2035, 0.84 billion tons by 2050;
- Energy intensity: should decrease 28% by 2025, 55%by 2035, 68% by 2050;
- Renewable energy utilization: the share of MSW should reach 5% by 2025, 12% by 2030, 16% by 2050;
- Supporting technologies: The cement industry develops new dry kiln decomposition technology to intake more natural gas and electricity; improves the proportion of new dry process cement clinker; actively promotes energy-saving grinding equipment and implement energy-saving retrofit of existing

large and medium-sized rotary kiln, mill and dryer. Gradually phase out the machine shaft kiln, wet kiln, dry hollow kiln and other backward cement production processes.

Nonferrous Metals

- Aluminium: Energy intensity decreases 6% by 2025, 14%by 2030, 54% by 2050;
- Aluminium recycling rate: 29% by 2025, 43% by 2035, 58% by 2050
- Supporting technologies: Copper smelting should adopt advanced oxygen-rich flash and oxygen-rich molten pool smelting process to replace traditional processes such as reverberator furnace, blast furnace and electric furnace to improve smelting strength; alumina should gradually eliminate direct heating and melting technology; The aluminium production should adopt large-scale pre-bake electrolytic cell, and the self-baked electrolytic cell is eliminated within a time limit, and the small pre-baked trough is gradually eliminated; the lead smelting production adopts the new technology of oxygen bottom blowing and other direct oxygen lead-smelting technology, transforms the sintering blast furnace process, and eliminates the soil method. Lead smelting; zinc smelting production develops new wet process and eliminates zinc smelting.

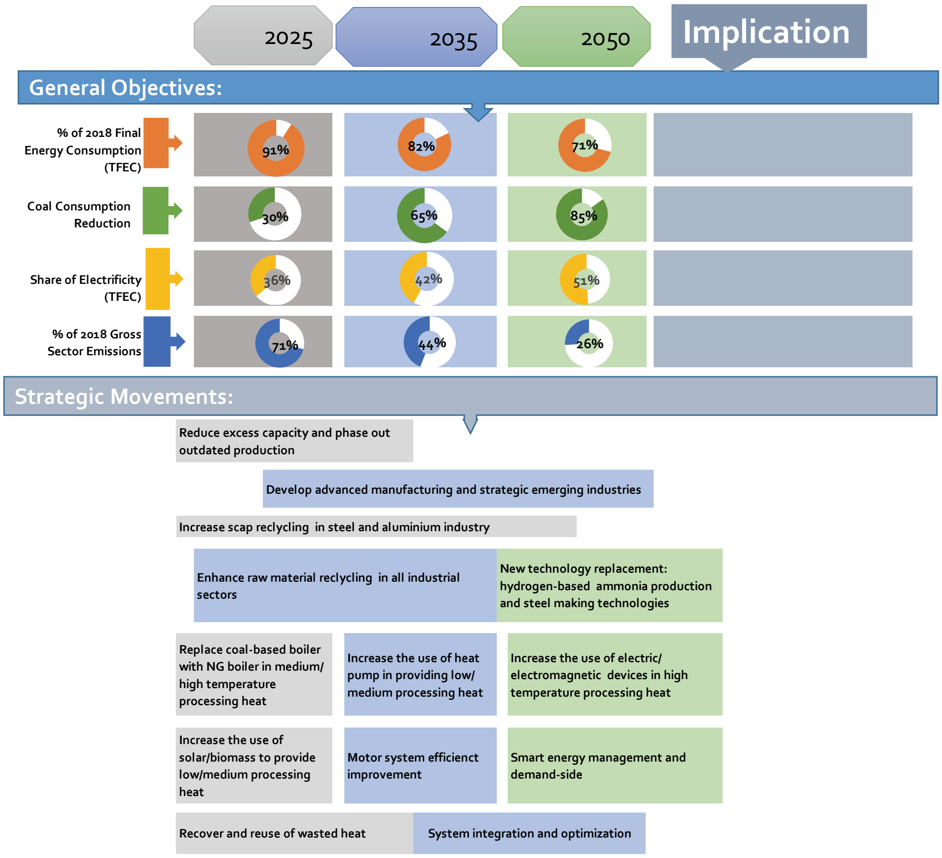
Chemicals

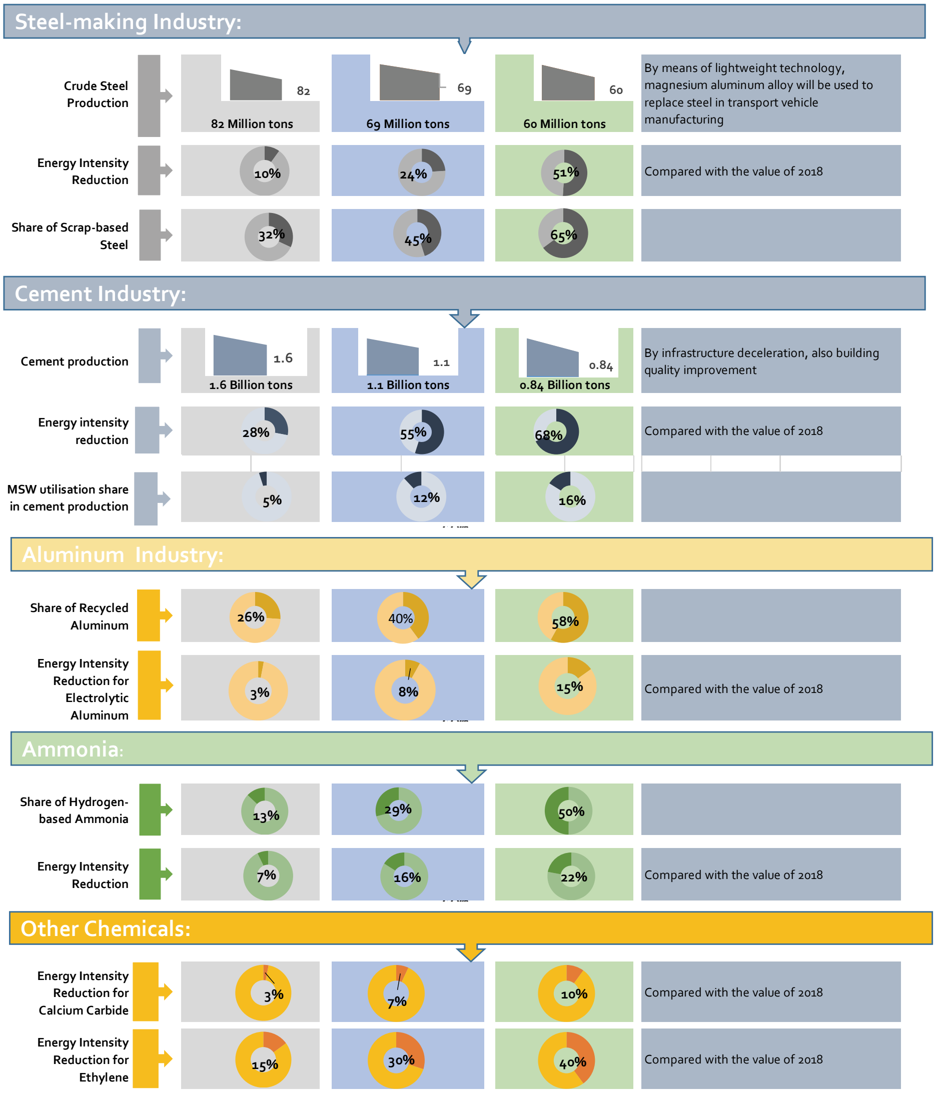
- Ammonia: Energy intensity decreases 6-8% by 2025, 14-17%by 2030, 20-23% by 2050
- Calcium carbide: Energy intensity decreases 3% by 2025, 7% by 2030, 10 % by 2050
- Ethylene: Energy intensity decreases 15% by 2025, 30 %by 2030, 40% by 2050
- Soda coda: Energy intensity decreases 5% by 2025, 11%by 2030, 19% by 2050
- Supporting technologies: Large-scale ammonia plant adopts advanced energy-saving technology, new catalyst and high-efficiency energy-saving equipment to improve conversion efficiency and strengthen waste heat recovery and utilization; synthetic ammonia with natural gas as raw material to promote one-stage flue gas waste heat recovery technology and transform steam system; synthetic ammonia with petroleum as raw material. Accelerate the replacement of feedstock oil with clean coal or natural gas; small and medium-sized synthetic ammonia uses energy-saving equipment and pressure swing adsorption technology to reduce energy consumption. Coal gasification uses coal water slurry or advanced powder coal gasification technology to replace traditional fixed bed gasification technology. The caustic soda production gradually phases out the graphite anode diaphragm caustic soda to increase the specific gravity of the ion-exchange membrane caustic soda. Soda ash production eliminates high-

energy-consuming equipment, adopts equipment large-scale, and automation measures.

Strategic roadmap

The final figures in this chapter illustrate the strategic roadmap for achieving the objectives enshrined in this chapter for China's industry sector.





Steel-making Industry:
Crude Steel Production
82
82 Million tons
69
69 Million tons
60
60 Million tons
By means of lightweight technology, magnesium aluminum alloy will be used to replace steel in transport vehicle manufacturing
Energy Intensity Reduction
10%
24%
51%
Compared with the value of 2018
Share of Scrap-based Steel
32%
45%
65%
Cement Industry:
Cement production
1.6
1.6 Billion tons
1.1
1.1 Billion tons
0.84
0.84 Billion tons
By infrastructure deceleration, also building quality improvement
Energy intensity reduction
28%
55%
68%
Compared with the value of 2018
MSW utilisation share in cement production
5%
12%
16%
Aluminum Industry:
Share of Recycled Aluminum
26%
40%
58%
Energy Intensity Reduction for Electrolytic Aluminum
3%
8%
15%
Compared with the value of 2018
Ammonia:
Share of Hydrogen-based Ammonia
13%
29%
50%
Energy Intensity Reduction
7%
16%
22%
Compared with the value of 2018
Other Chemicals:
Energy Intensity Reduction for Calcium Carbide
3%
7%
10%
Compared with the value of 2018
Energy Intensity Reduction for Ethylene
15%
30%
40%
Compared with the value of 2018

7. Transportation development roadmap

As the economy of China develops towards an abundant service-based economy, the transport sector of the country sees large changes. Despite the fact that the transport demand will significantly increase, the growth of final energy consumption of transport sector can be managed at a moderate level in the long term thanks to the high penetration of electric vehicles. A large electric vehicle stock can also serve as a valuable flexibility resource for variable renewable energy. The electrification of transport sector, particularly for heavy duty freight vehicles, could be enhanced through the introduction of fuel cell vehicles running on electrolyte hydrogen, which has a large cost reduction potential in B2 scenario.

The increased transport need can either cause air pollution in cities or it can help the balancing of the electricity grid, dependent on the technology track chosen. China is already well underway with high targets for EV implementation and progressive fuel standards.

7.1. Main findings

Ownership of vehicles and general passenger transport continues to increase. The ownership for passenger cars shall continue to grow steadily and reach 450 million by 2050. There will also be a shift from air passenger transport high-speed rail in non-road passenger transport, due to of high-speed rail's environmental effectiveness and economic efficiency.

Freight transport demand will lag due to the 'new normal' transition and the reduced need for cargo transport. Moreover, market pressures will drive the productivity of freight transport on from the roads to less energy-intensive modes such as railways and ships.

A controlled growth in final energy consumption of transportation sector. Despite the increasing transportation demand and the rise in ownership of passenger vehicles, the final energy consumption of the entire transportation sector peaks around 2030 at 643 Mtce, then decreases to 491 Mtce by 2050 in Stated Polices Scenario. In Below 2 °C Scenario, it peaks around 2030 at 614 Mtce and falls back to 467 Mtce by 2050.

Vehicles adopts a cleaner fuel mix. China's fossil fuel demand for transport is projected to peak around 2026-2027 at 550-570 Mtce. The share of oil product in transportation fuels continues to decline over the projection period, from 95% in 2018 to 32%- 45% in 2050. Electricity will become the fast-growing fuel types in future traffic energy consumption. Its share grows from 2% in 2018, to 33%-39% in 2050. By 2047, electricity shall replace oil products as the dominant energy in the Below 2 °C scenario.

Strong growth of electric vehicles. Along with policy incentives and technology advances, the cost of electric vehicles will reduce greatly. Electric vehicles and plug-in hybrid vehicles will be the main route for China's new energy vehicles' development long-term. According to our analysis, 450-490 million electric vehicles (including both passenger and freight) are expected on road by 2050. To achieve that, China needs to introduce stricter regulation to control new ICE sales in the 14th-15th FYP.

Improved energy efficiency. The domination of EV will introduce substantial improvements on average fuel economy due to their efficiency advantages compared to the current ICE engines power. New propulsion systems including electric motors powered by batteries or fuel cells, battery performance boost, and various fuel hybrid concepts could offer significant reductions in energy intensity as well as carbon emissions. Moreover, automated and connected vehicles could also help to further lower fuel consumption and GHG emissions.

Added flexibility. A high penetration of EV's will support the power system transformation and EV owners can benefit from providing flexibility and system services to the grid. Used EV batteries are can be repurposed for stationary storage at low cost and play a role in distributed and aggregated energy storage.

Flexibility from active EV's have limitations, mostly due to transport service times, charging power limits and time at charger. Chapter 9 includes analysis of the potentials by EV smart charging and its limitations. The positive effects of EVs for the power system and security of supply in the grid is only achieved by using smart charging, as regular charging causes a large pool of vehicles to charge concurrently to residential peak energy consumption, putting unnecessary strain on the grid. The total battery capacity available from active EV batteries (not counting PHEVs) is 32.7-38 TWh by 2050. The electricity grid will be able to utilise a large part of this capacity for flexibility.

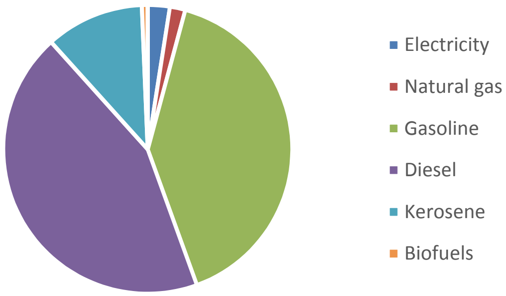
Decoupling of transportation development and carbon emissions. Despite the strong increase of transport demand, by 2050, the direct CO_2 emission are only 340-480 million tonnes in the two scenarios, which is 40-55% of the 2018 level. This requires government focus on technical innovation and promoting EVs as much as possible for early carbon emissions peaking, realizing the decoupling between transportation development and carbon emissions. Beyond EVs, biofuels and P2X provides alternative decarbonised transport fuel particularly for heavy-duty transport, where long running hours makes battery EVs less suitable.

7.2. The current situation

Gasoline and diesel dominate the transportation energy use

Together, these two fuels accounted for 84% of total delivered transportation energy in 2018. Gasoline consumption is primarily for the movement of people, especially by light-duty vehicles. Diesel fuel consumption is primarily for the movement of goods, especially by heavy-duty trucks. Jet fuel accounts for 11% of transportation energy consumption, while Natural gas and electricity together accounting for about 4%. The current oil-dominant energy consumption of transportation is an energy security issue. It is imperative to adjust and optimize the energy consumption structure of the entire transport sector.

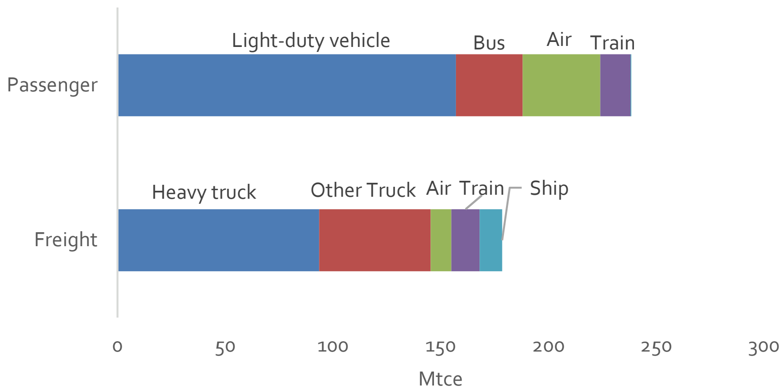
Figure 7-1: China's transportation energy mix in 2018[220]



On-road vehicles demand the most of transportation energy

Figure 7-2 shows that road vehicles currently dwarf other modes of transportation in China. The energy consumed by light-duty cars accounts for 65% in passenger transport energy and heavy-haul trucks account 52% in freight transport. Air travel accounts for only nearly 11% of total transportation energy consumption, with trains and ships accounting for 7% and 4% respectively.

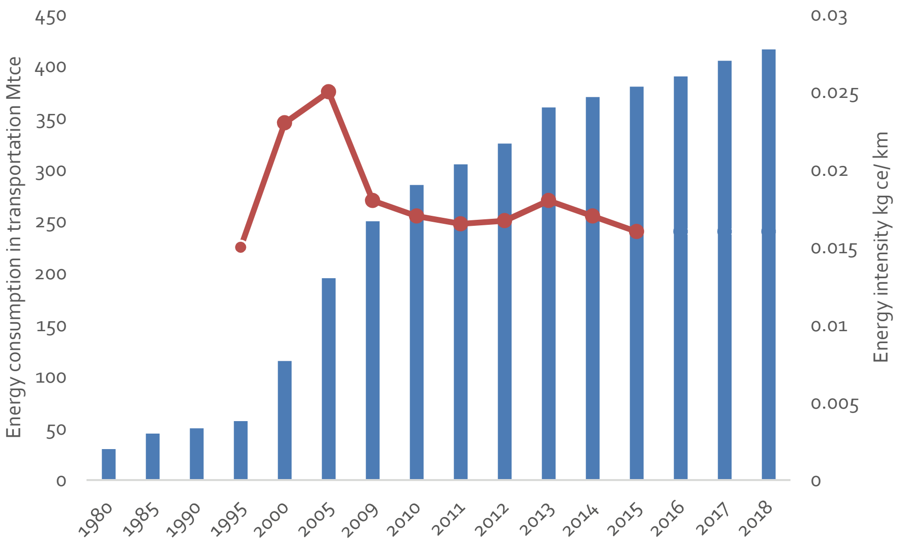
Figure 7-2: Energy consumption of different transportation modes in 2018



Fast growth with high energy intensity

Energy consumption in transport has grown rapidly in China since 2000, caused by rapid growth of its passenger car fleet. Automobile sales in 2016 reached 27.5 million and the total stock surpassed 194 million, 10 times higher than in 2000. Total transport energy consumption reached 416 Mtce in 2018, 10 times of that in 1980. This high energy-intensive transport has replaced modes with lower intensities. The share of rail and ship transport is declining. Given the opportunity, people prefer travel with private cars over public transportation. Since 1995, the traffic energy intensity even increased for 10 years. Despite technology improvements, the energy intensity in 2014 is still higher than that of 1995.

Figure 7-3: Energy consumption and energy intensity[221]



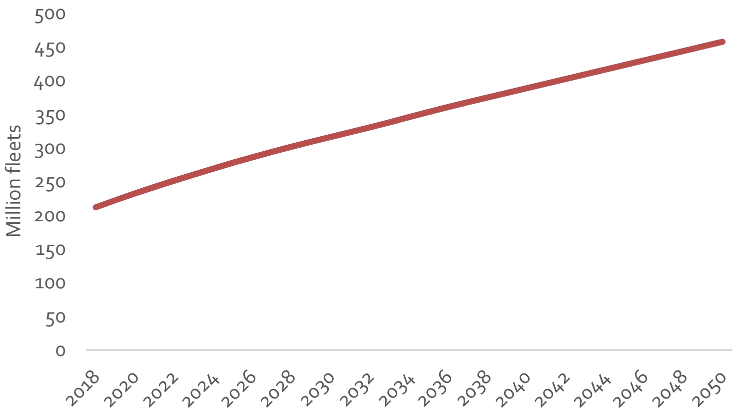
7.3. Future development trend

Passenger on-road transport

The Chinese auto market, which has continued its strong growth for many years, entered a negative growth zone in 2018. Even though, China's automobile sales have still ranked the first in the world for 10 consecutive years, with an annual sale of nearly 30 million vehicles, and the national car ownership is above 200 million. Nevertheless, China's current per capita ownership only is 0.14, far below the level of 0.8 cars in the United States (Figure 7-4). To ensure a healthy transportation development, national authorities (NDRC and three others) jointly issues policies to release the restriction on vehicle ownership, particularly for new energy vehicles. With these, local authorities can incentivise people to purchase and operate new energy vehicles, using differentiated parking prices, registration fees and driving restrictions, etc.

Considering China's low per capita car ownership, and its market stimulating polices, China's future car ownership expects to continue its steady growth. By 2035, national passenger car ownership will reach 320 million; by 2050, it will reach 450 million.

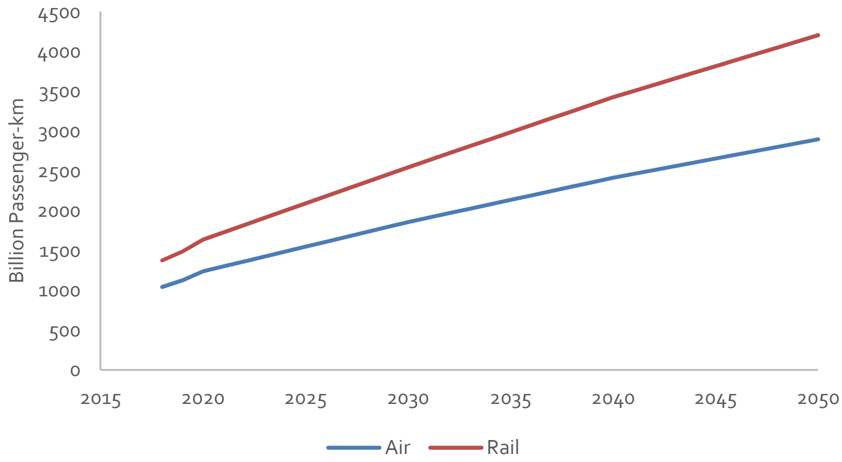
Figure 7-4: Car ownership projection



Passenger non-road transport

The projection for non-road transportation, especially the passenger flights increases rapidly throughout the forecast period. With higher affluence, the Chinese population will travel as much as North Americans and Europeans today, both domestically and internationally. In both scenarios it is assumed that per capita flying to be equal to Western Europe by 2050. Total non-road transport is 7100 billion passenger-km by 2050. High-speed rail transport has significant advantages over short-haul flights, other than much lower energy intensity and clean fuel. Urban station locations, larger luggage capacity and faster check-in process means that high-speed rail competes well with flights well for trips around 800 km, but equally does so even at the 1500 km distance between Beijing and Shanghai. By focusing on these advantages, China can mitigate substantial GHG emissions. With good infrastructure and good planning, the model assumes more growth in high-speed rails than for flights.

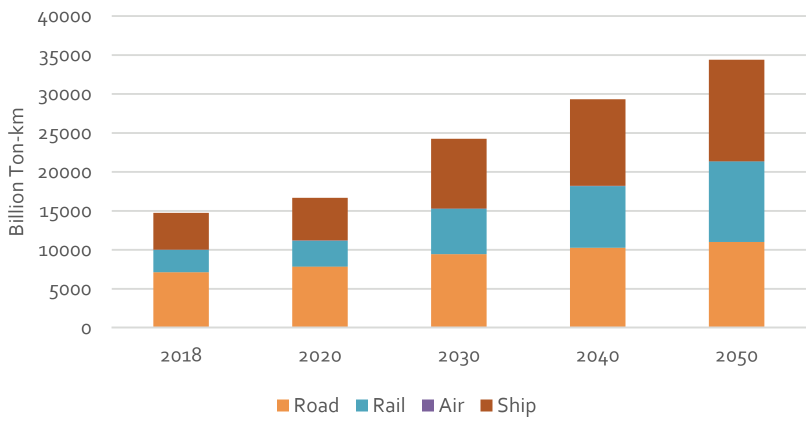
Figure 7-5: Future growth in China air and rail travel



Freight transport

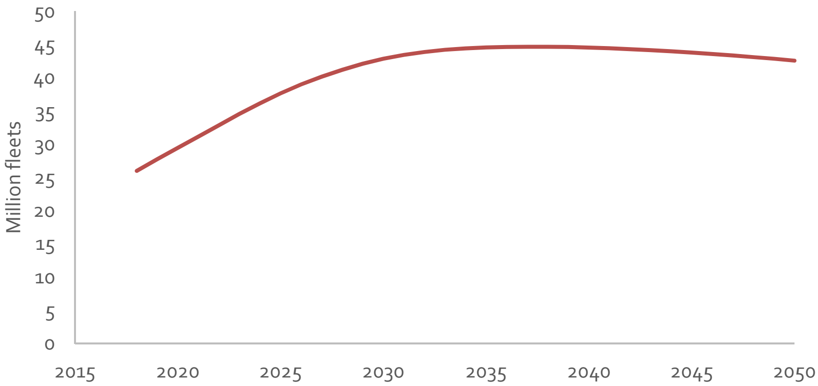
Freight transport demand relates closely to economic development. By 2050, the total freight transport turnover reaches billion 34500 ton-km. In 2050, better transport policies and intelligence balances the freight transport much better than today, as shown in Figure 7-6. On-road freight only yields limited growth by 2050. As the energy intensity of road trucks is much higher than that of waterway shipping, this transport mode overtakes trucks in around 2030 to become the dominant freight transport mode. Freight movement shifts to more energy efficient transport modes, such as ships and railway, which grows by 180% and 260% respectively by 2050 compare with 2018 level.

Figure 7-6: Future non-road freight turnover



Under such on-road freight turnover, the projected truck fleet ownership stabilizes around 2035, at about 45 million trucks, and then slightly decline to 43 million by 2050 due to the improvement of the average annual mileage.

Figure 7-7: Future on-road freight turnover



More efficient vehicles

In terms of energy efficiency improvement, there's still 35-40% of energy saving potential for ICE vehicles, through advanced engines, homogeneous charge compression ignition, continuous variable transmissions, and lightweight technologies, etc. The energy-saving potential for hybrid vehicles is even larger. With the development of technology, the fuel consumption of normal-sized ICE passenger vehicles reduces from the current 6.4 L/100 km to 2.3.8 L/100 km by 2050, while PHEV vehicles of the same type decreases to 2.4 L/100 km.

Electric vehicles are more adaptable to the future transition to an intelligent transportation than ICE vehicles, due to that they could easily be digitalized and connected to the grid. With the development of new technologies and formats such as autopilot, car sharing, driver assistance, partial/ conditional/high/full automation technologies in the future, vehicles utilizes advanced sensors for instantaneous monitoring and precise control of vehicle operation, which will boost energy efficiency.

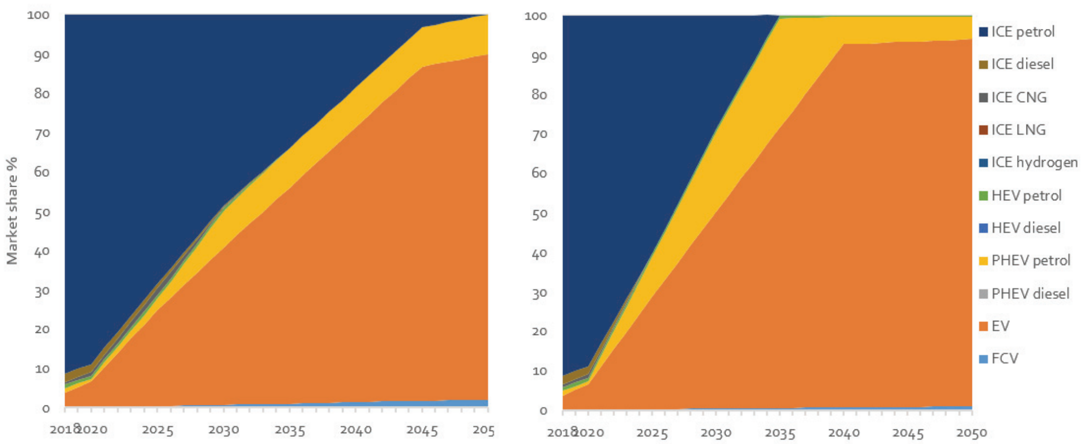
A thorough electrification: Passenger vehicles

As battery technology continually improves, so does the economy of electric vehicles. In 2018, the energy density of the domestic power battery system was approx. 200 Watt-hours/kg, with the driving distance for a normal vehicle being up to 400 km, comparable to the gas equivalent on a full tank. By 2020 and 2025 the projected battery energy density reaches 250 watts/kg and 300 watt-hours/kg, which enables a continuous drive more than 600 kilometers.

Considering EVs are already superior to ICE vehicles in terms of acceleration, controlling system and noise, the driving experience of EVs will surpass that of ICE vehicles by 2025.

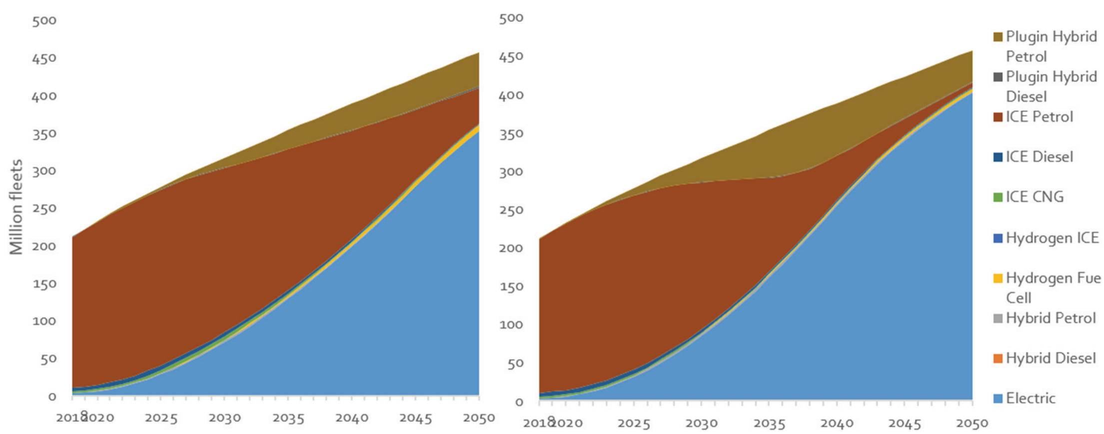
Therefore, for the passenger car, both scenarios show fast electrification: in the Stated Policies scenario, by 2030, the total sales of pure EV and plug-in hybrid vehicles (PHEV) accounts for 50% of all passenger vehicle sales. In the Below 2 °C scenario, the sales share of the above two vehicle types reaches 70% by 2030; by 2035, the Below 2 °C scenario realizes a 100% electric vehicle sales market.

Figure 7-8: Annual sales shares of passenger cars in Stated Policies (left) and Below 2°C (right) scenarios



Vehicle lifetimes affect the stock efficiency, given the lag in retirement of older vintage, less-efficient vehicles. Under the above sales projection, the Stated Policies scenario estimates the new energy vehicles in China to represent 45% of the passenger vehicle stock in 2035 and 89% in 2050. In the Below 2 °C scenario, by 2035 the new energy vehicles in China shall account for 64% of the stock in 2035 and 98% in 2050.

Figure 7-9: Stock share of passenger cars in Stated Policy scenario (left) and Below 2 °C scenario (right)

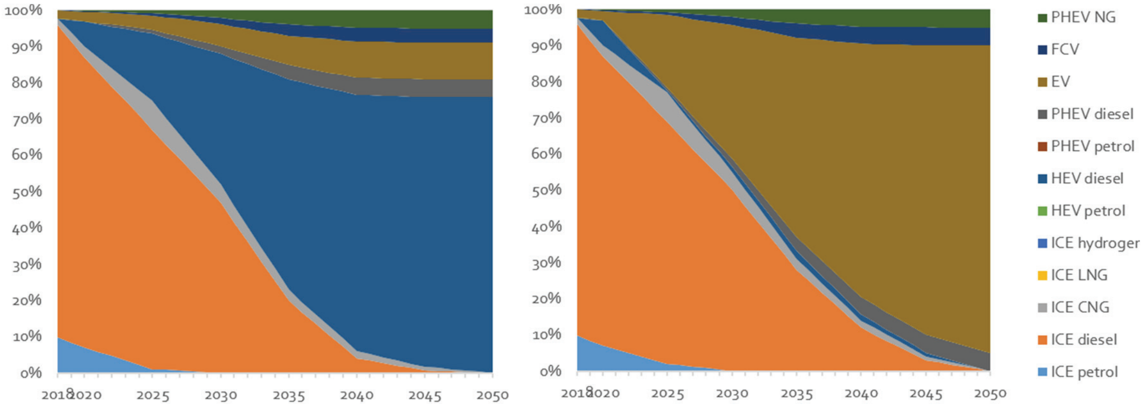


A thorough electrification: Light trucks

As for the light trucks, electrification shall be significantly faster than passenger vehicles, due to the strong policy promotion. After the issue of "Blue Sky" plan, local governments took actions to phase out ICE vehicles in urban buses, postal services, taxis, urban logistics and other transportation. According to the statistics, by now 22 provinces have issued relevant documents to fully electrify their bus fleet. The Ministry of Transport has proposed that by the end of 2020, all the buses in municipalities, provincial capitals, and cities with separate plans is with new energy vehicles. In addition, due to the long driving mileage, the economy of electric light trucks is even better than for personal vehicles, which greatly improves transition acceptance.

The Stated Policy scenario projects diesel-based hybrid technology to rapidly penetrate the light and medium sized truck market. By 2030, HEV market share will reach 1/3 of stock, and exceed 70% by 2050. Under the Below 2 °C scenario, the EV technology route is favoured. In 2030, the market share for EVs reaches 37% and increase to 85% by 2050.

Figure 7-10: Annual sales shares of light trucks in Stated Policy scenario (left) and Below 2 °C scenario (right)

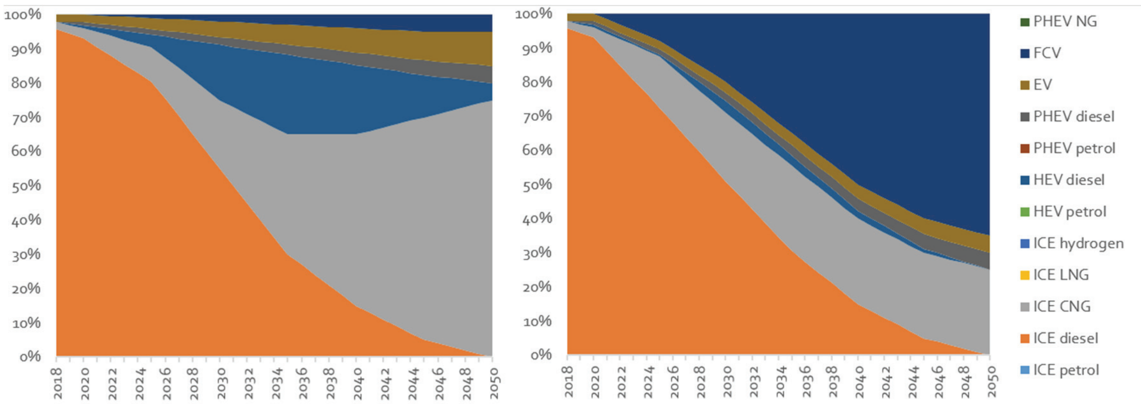


A thorough electrification: Medium and heavy trucks

For the medium and heavy-duty trucks, there is still a certain challenge to be fully electrified in the short term. On one hand, more batteries in the car increase the total consumption due to the additional weight, on the one, higher-capacity batteries further push up the prices. Additionally, the medium and heavy trucks industries have alternatives to electric vehicles, such as natural gas vehicles, hybrid vehicles, and fuel cell vehicles. Such routes are technically feasible for heavy freight transportation, but have other challenges, such as pollutant emissions, costs, and lacking infrastructure networks. There is a large uncertainty in the future truck market structure.

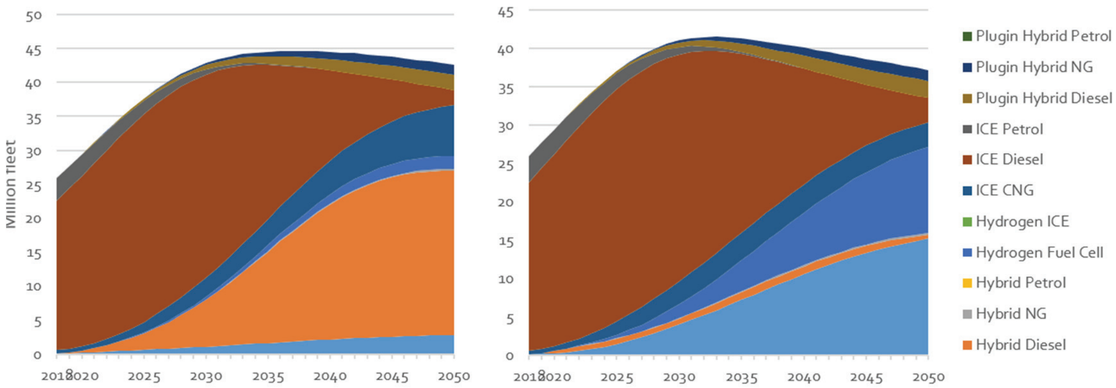
In the Stated Policy scenario, the penetration rate of each alternative fuel technology route increases to different degrees. The fossil fuel-based HEV has the fastest growth rate, accounting for 45% of all medium and heavy-duty truck sales by 2050; the Below 2 °C scenario promotes electrolytic hydrogen-based fuel cell technology. Medium and heavy-duty fuel cell vehicles begin commercialization by 2030, accounting for 80% of all medium and heavy-duty freight vehicle sales by 2050.

Figure 7-11: Annual sales shares of heavy trucks in Stated Policy scenario (left) and Below 2 °C scenario (right)



As for the stock penetration, the two scenarios show more differences. The Stated Policy scenario projects that by 2050, HEV market share will reach 57%, and the ICE truck will still hold 23% of the stock, PHEVs accounts for 9 %, EVs 7% and hydrogen fuel cell truck 5%. Under the Below 2 °C scenario, the EV technology route is also favoured in trucks. By 2050, EV stock share reaches 41%, followed by hydrogen fuel cell trucks, about 30%. ICE trucks and PHEV shall account 17% and 10% respectively.

Figure 7-12: Stock share of trucks in Stated Policy scenario (left) and Below 2 °C scenario (right)



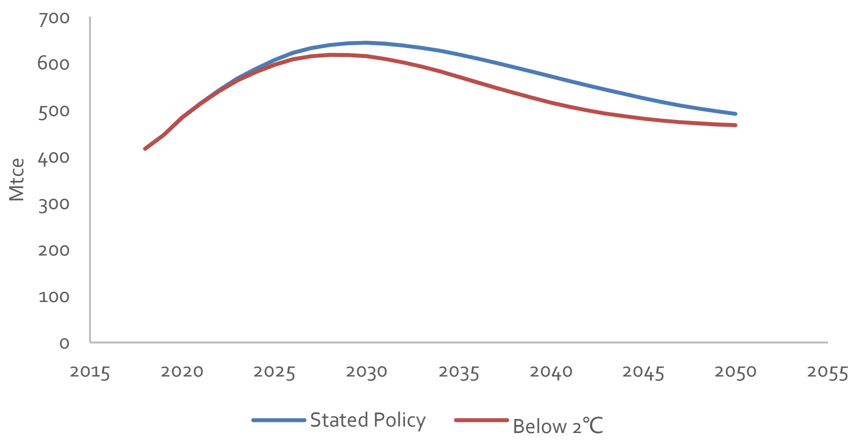
7.4. A vision into future transportation

Final energy consumption in transportation

The final energy consumption in transportation sees a fast growth in the first few years in both scenarios. The compound annual growth rate before the peak is about 3.7% in In Stated Policy Scenario, and 3.3% in Below 2 °C Scenario. Specifically, the growth rate before 2022 will be faster and the annual growth rate will exceed 5%.

Stated Policy Scenario projects the final energy consumption in transportation to peak around 2030 at approximately 645 Mtce. After this, it falls back to 490 Mtce by 2050, due to the increased EV share in the total vehicle stock. In Below 2 °C Scenario, it shows slower increase, corresponding to the faster electrification measures. Transport energy consumption peaks also around 2030 at 620 Mtce and declines to 465 Mtce by 2050. Despite the rise in ownership and use of passenger vehicles, China does not see major changes in the total final energy consumption for transportation in 2050. Compared with 2018, the final energy consumption only increases 12% and 18% in 2050 in the two scenarios. This is while fossil fuel consumption decreases.

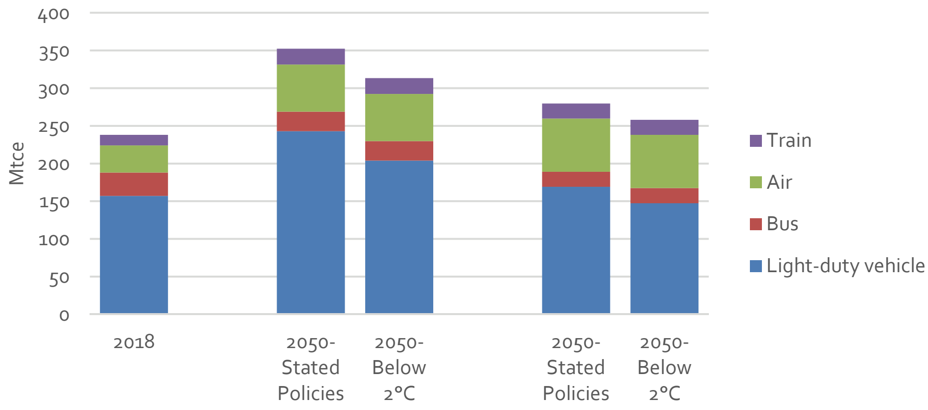
Figure 7-13: The final energy consumption in transportation in two scenarios



Energy consumption by mode

In the Stated Policy scenario, energy consumption for passenger transport rises from 240 Mtce in 2018 to 350 Mtce in 2035, then falls to 280 Mtce in 2050 (Figure 7-14). In Below 2 °C scenario, it grows to 315 Mtce by 2035 and 260 Mtce by 2050. Light-duty vehicles' energy consumption still accounts the biggest share, around 60-70% in the forecast period. Aircraft's energy consumption shows stable increase, from 36 Mtce in 2018 to 71 Mtce in 2050, with a share increasing from 15% in 2018 to 18% in 2035, and 25% in 2050. The energy consumption of railways firstly increases from 13 Mtce and stabilises around 2035 at 22 Mtce.

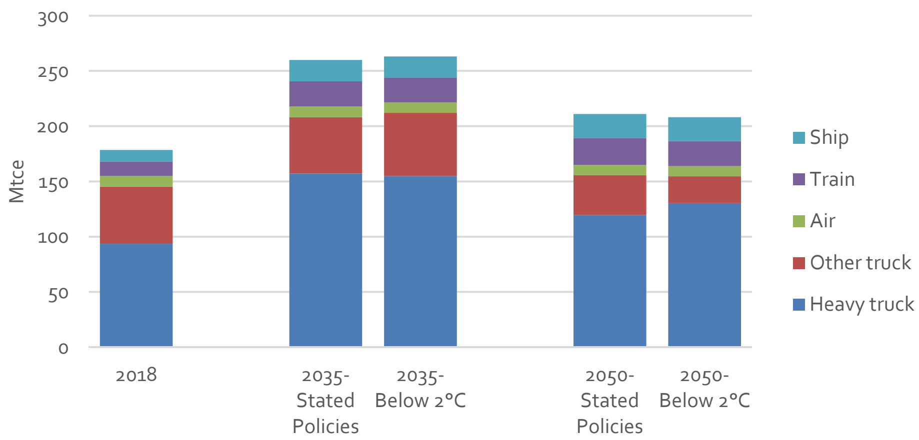
Figure 7-14: Energy consumption by mode for passenger transport in two scenarios



Freight transport energy consumption shows a similar trend with the passenger transport. It grows from 238 Mtce in 2018, reaches 350 Mtce and 315 Mtce for 2035 in the Stated Policies scenario and Below 2 °C scenario respectively, and then falls to 280 Mtce and 260 Mtce in 2050.

On-road truck will continue to be the major source of freight transportation, the sum all trucks energy consumption accounts 55%-65% of the freight related energy consumption. Heavy trucks see its share increasing yearly, while the light trucks have a gradual decline. The proportion of waterways and railway freight transportation shows stable increase, both from 6-7 %in 2018 to 10-11% in 2050.

Figure 7-15: Energy consumption by mode for freight transport in two scenarios

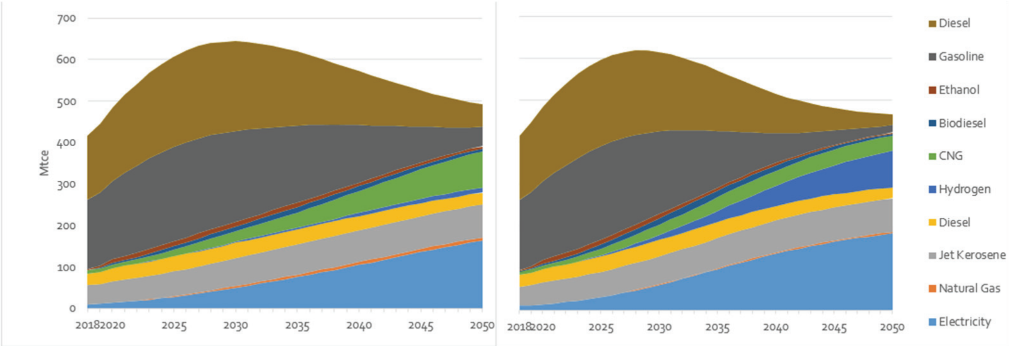


Energy consumption by fuel

With the rapid transition towards new energy vehicle technologies, and the expansion of electric non-road transport, China's dependence on fossil fuel is projected to peak around

2027 at 573 Mtce in the Stated Policy Scenario, 42% above the 2018 level; and 545 Mtce around 2026 in the Below 2 °C Scenario. After that, the main trend will be the substitution of petroleum products with electric drive and other alternative fuels. By 2050, China will only consume 75% and 50% as much fossil fuel for transport as compared to 2018 levels in the two scenarios respectively. Most transport fossil fuel use will come from oil products, with jet fuel as the largest share.

Figure 7-16: Energy consumption by fuels in Stated Policy scenario (left) and Below 2 °C scenario (right)

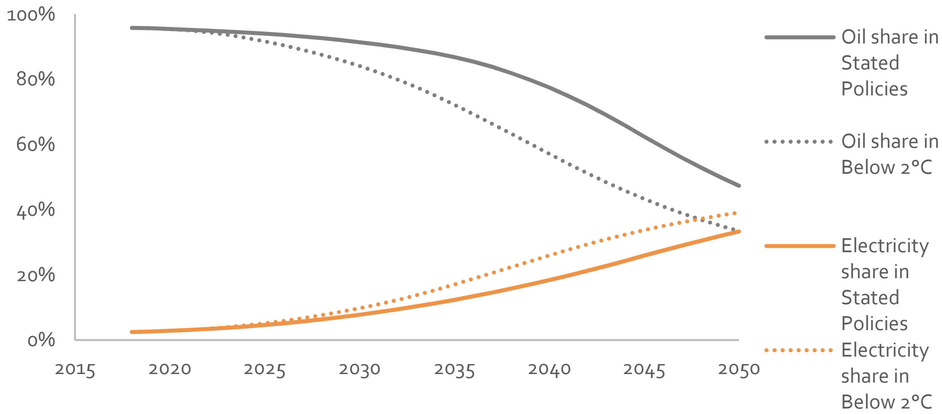


The share of oil product in the total transportation energy continues to decline over the projection period, from 95% in 2018 to 83% and 68% in 2035 in the Stated Policy Scenario and Below 2 °C Scenario respectively, and then to 45% and 32% in 2050. Along with significant improvements in the efficiency of conventional ICE vehicles and the development of alternative fuels, the demand for diesel and gasoline in 2050 will only be 25-54 Mtce and 20-47 Mtce in the two Scenarios, 65-90% less than the level in 2018. Aviation kerosene demand will maintain a growth rate of 1.7% during the 2018-2050 period.

Electricity will become the fast-growing fuel types in future traffic energy consumption. Its share grows from 2% in 2018, to 33% in 2050 in the Stated Policy Scenario, and 39% in in the Below 2 °C Scenario. By2047, electricity replaces oil products as the dominant energy in the Below 2 °C Scenario.

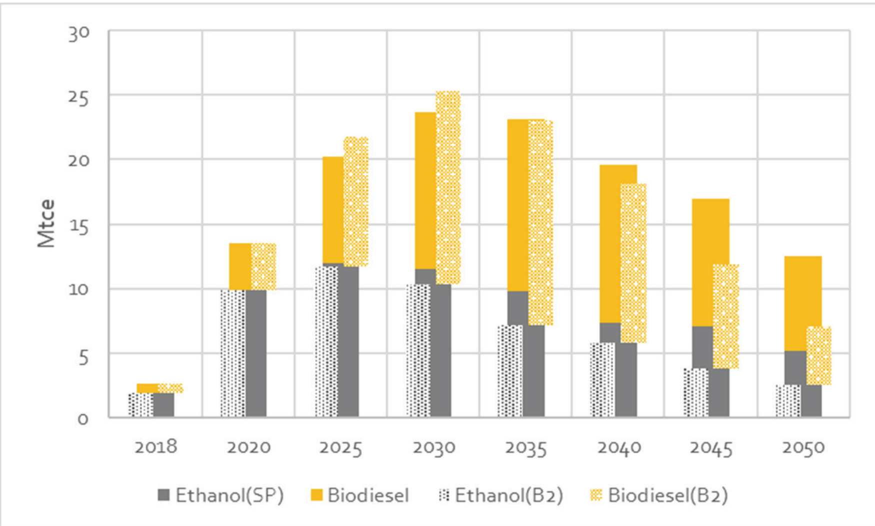
The systems introduce electricity-based hydrogen, which share grows to 3% in the fuel mix in 2050 in the Stated Policy Scenario and 19% in the Below 2 °C Scenario.

Figure 7-17: Share of Oil and electricity in transport energy consumption



Biofuels (ethanol and biodiesel) represent the majority share of renewables in global energy demand for road transport. Blending mandates drives biofuel demand and expects to see nine-fold growth to around 25 Mtce by 2030. After that, the biofuel demand, especially for gasoline, shall experience a decline due to the retirement of ICE vehicle stock.

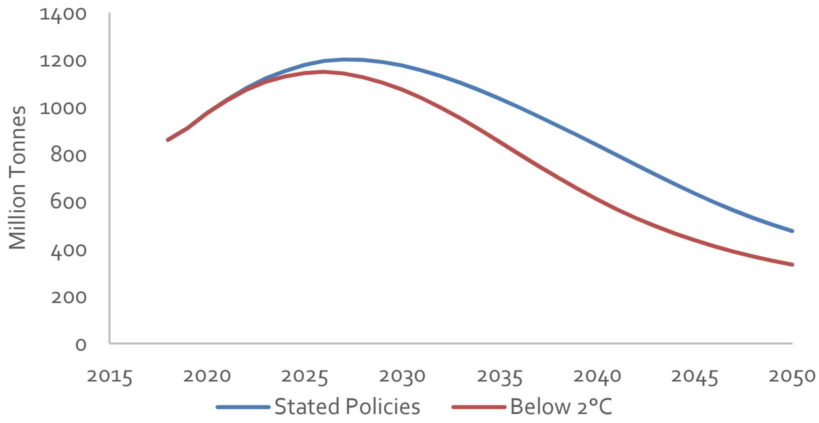
Figure 7-18: Biofuel consumption in two scenarios



CO2 emission in transportation

In 2018, the transport sector emitted around 860 million tonnes CO2. Carbon emissions will peak around 2026-2027 at 1150-1200 million tonnes, and then decline until 2050, despite the strong increase of movement demand, realizing the decoupling between transportation development and carbon emissions. By 2050, the direct CO2 emission are only 340-480 million tonnes in the two scenarios, 40-55% of 2018 level.

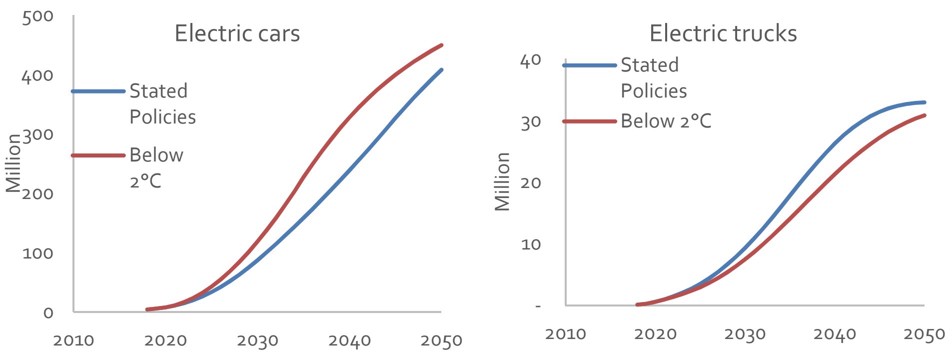
Figure 7-19: Direct CO2 emission from transport **in two scenarios**



Flexibility introduced by EVs

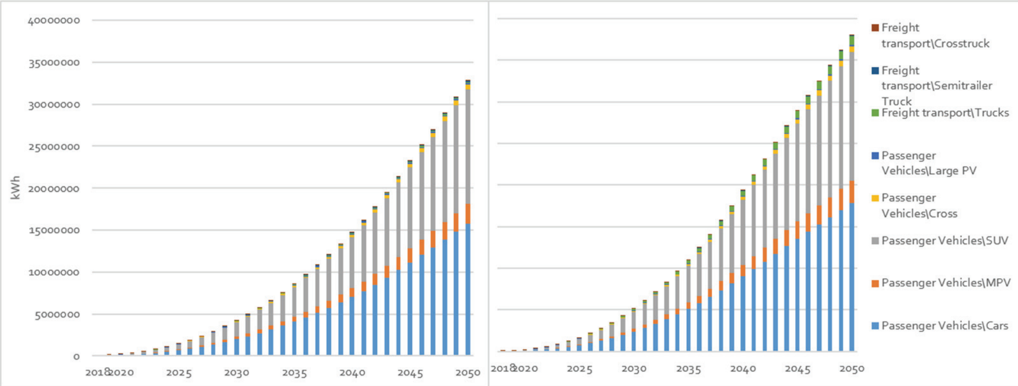
Demand-side response technology is expected to be widely used by 2030. Electric vehicles are used as miniature energy storage power stations and have sufficient capacity for power system peaking in cities. In the State Polices scenario, it is estimated that by 2050, there will be 450 million electric vehicles on road (for both passenger and freight), and in the Below 2 °C scenario the number will further grow to 490 million.

Figure 7-20: Electric vehicle development (left) and electric truck development(right)



The high penetration of electric vehicles not only intake large amounts of variable renewable energy, but also contribute their batteries to auxiliary services such as peak regulation and frequency modulation. Used EV batteries are can be repurposed for stationary storage at low cost and play a role in distributed and aggregated energy storage, providing a capacity of 32TWh for demand side management by 2050 in the Stated Policies scenario, and 38TWh in the Below 2 °C scenario.

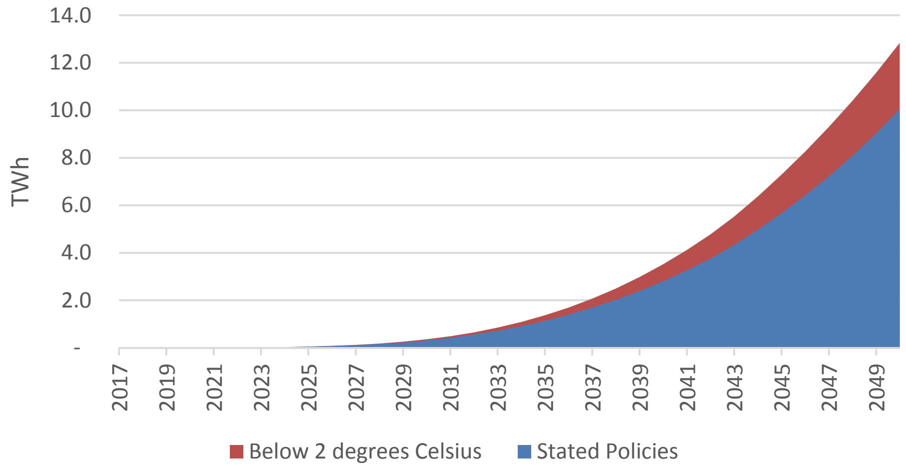
Figure 7-21: Vehicle-bound battery capacity in Stated Policies scenario (left) and Below 2 °C scenario (right)



Flexibility from active EV's have limitations, mostly due to transport service times, charging power limits and time at charger. Chapter 9 includes analysis of the potentials by EV smart charging and its limitations. The positive effects of EVs for the power system and security of supply in the grid is only achieved by using smart charging, as regular charging can cause a large pool of vehicles to charge concurrently to residential peak energy consumption, putting unnecessary strain on the grid. The total battery capacity available from active EV batteries (not counting PHEVs) is estimated to be 32.7-38 TWh by 2050. The electricity grid could utilise a large part of this capacity for flexibility.

Like all other vehicle types, electric vehicles expire and have limited lifecycles, though these may be longer than ICEs, due to better technology. Vehicle accidents, new technologies and battery replacement will all lead to surplus batteries that are no longer usable for vehicles. Recycling and disposal of batteries will improve, but wherever available, repurposing the batteries for stationary grid storage is preferred. Using survival rate assumptions and battery degradation forecasts, analysis shows between 10-12.8 TWh of available grid battery storage from repurposed EV batteries. This capacity is fully available to the grid operator, highly modular and very flexible, providing great value as reserve capacity in local grids.

Figure 7-22: Potential EV battery capacity ready for repurposing. Note that the Below 2 °C is added on top of the Stated Policies.



7.5. Transportation development roadmap

The quantitative analysis enables us to have a clear vision of the future, which shows it is possible to have a clean, safe, efficient, low-carbon energy system in transportation sector, be the following objectives and targets fulfilled.

Overall objectives and milestone targets

According to *Outline for Building China's Strength in Transportation*(交通强国建设纲要), which was jointly released by the Communist Party of China Central Committee and the State Council on Sep 19, 2019, China aims to raise its global competitiveness in the transport sector in three stages from now to 2050:

- By 2020, complete the tasks of the "13th Five-Year Plan" for building a modern transportation system, laying a solid foundation for the construction of a strong transportation country;
- From 2020 to 2035, building up a strong infrastructure in China. The modernized comprehensive transportation system has taken shape, the people's satisfaction has been significantly improved. It has developed fast and extensive network. The passenger transportation is convenient and smooth, the multi-modal freight transportation is diversified, efficient and economical; the transportation is generally intelligent, safe, green and shared. The urban traffic congestion is basically alleviated, and the barrier-free travel service system is basically perfect.
- From 2035 to 2050, a country with strong transportation network isperfected. The quality of infrastructures, technical equipment, technological innovation capability, are among the front ranks of the world. Traffic safety level,

governance capacity, international competitiveness and influence reach the international advanced level.

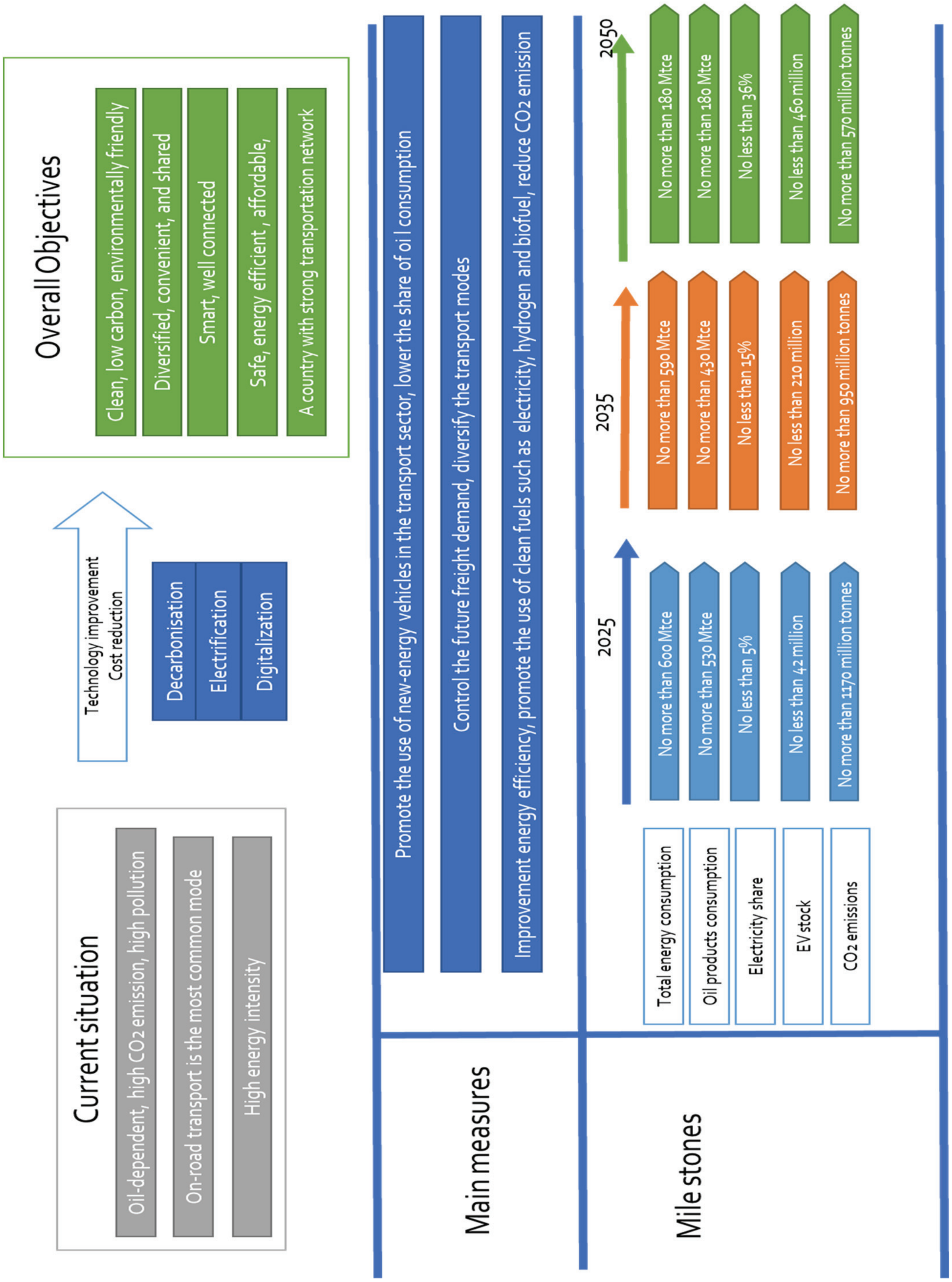
In order to reach the above objectives, the future energy system for transportation should be clean and low-carbon, diversified and convenient, intelligent and well connected, safe and energy efficient. In order to achieve this, the following milestone targets are specified:

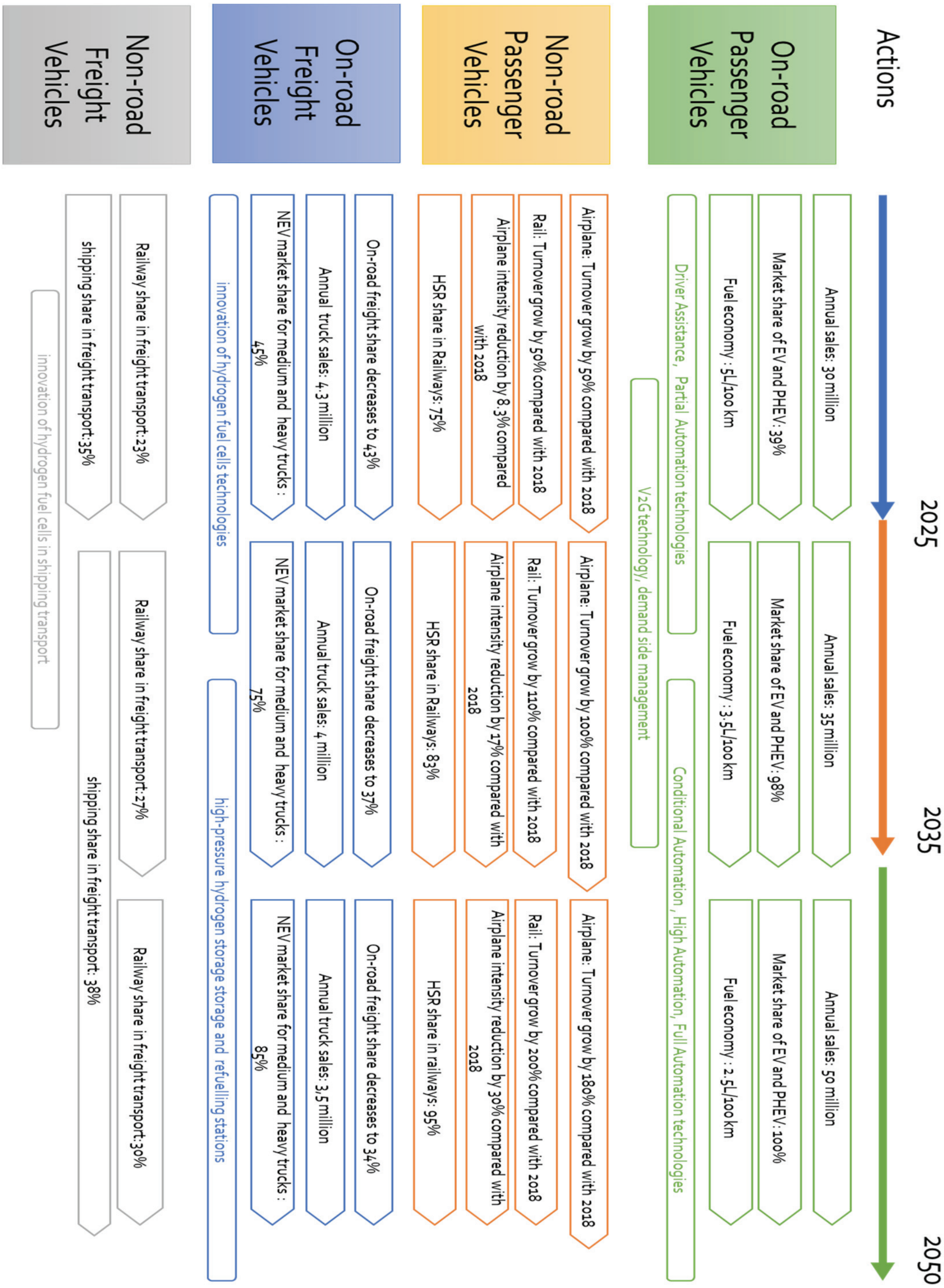
- Control the future transport demand increase, diversify the transport modes; Improvement energy efficiency and maintain the total energy consumption under control, especially the oil consumption.
  - By 2025, the total energy consumption should be no more than 600 Mtce, and the oil consumption no more than 530Mtce;
  - by 2035, the total energy consumption should be no more than 590 Mtce, and the oil consumption no more than 430Mtce;
  - by 2050, the total energy consumption should be no more than 480 Mtce, and the oil consumption no more than 180Mtce,

- Promote the use of new-energy vehicles in the transport sector, especially the electric vehicles' use,
  - by 2025, the electricity share in total energy consumption should no less than 5% and the EV stock less than 42 million;
  - by 2025, the electricity share in total energy consumption should no less than 15% and the EV stock less than 210 million;
  - by 2050, the electricity share in total energy consumption should no less than 36% and the EV stock less than 460 million;
- Promote the use of clean fuels such as electricity, hydrogen and biofuel, reduce CO_2 emission:
  - by 2025, CO_2 emission should no more than 1170 million tonnes;
  - by 2035, CO_2 emission should no more than 950 million tonnes;
  - by 2050, CO_2 emission should no more than 570 million tonnes;

Strategic roadmap

More detailed work plans in each transportation mode could be found in the following roadmaps:


Current situation
Oil-dependent, high CO2 emission, high pollution
On-road transport is the most common mode
High energy intensity
Technology improvement
Cost reduction
Decarbonisation
Electrification
Digitalization
Overall Objectives
Clean, low carbon, environmentally friendly
Diversified, convenient, and shared
Smart, well connected
Safe, energy efficient, affordable,
A country with strong transportation network
Main measures
Promote the use of new-energy vehicles in the transport sector, lower the share of oi l consumption
Control the future freight demand, diversify the transport modes
Improvement energy efficiency, promote the use of clean fuels such as electricity, hydrogen and biofuel, reduce CO2 emission
Mile stones
2025
2035
2050
Total energy consumption
Oil products consumption
Electricity share
EV stock
CO2 emissions
No more than 600 Mtce
No more than 530 Mtce
No less than 5%
No less than 42 million
No more than 1170 million tonnes
No more than 590 Mtce
No more than 430 Mtce
No less than 15%
No less than 210 million
No more than 950 million tonnes
No more than 180 Mtce
No more than 180 Mtce
No less than 36%
No less than 460 million
No more than 570 million tonnes


Actions
2025
2035
2050
On-road Passenger Vehicles
Annual sales: 30 million
Market share of EV and PHEV: 39%
Fuel economy : 5L/100 km
Driver Assistance, Partial Automation technologies
V2G technology, demand side management
Annual sales: 35 million
Market share of EV and PHEV: 98%
Fuel economy : 3.5L/100 km
Conditional Automation, High Automation, Full Automation technologies
Annual sales: 50 million
Market share of EV and PHEV: 100%
Fuel economy : 2.5L/100 km
Non-road Passenger Vehicles
Airplane: Turnover grow by 50% compared with 2018
Rail: Turnover grow by 50% compared with 2018
Airplane intensity reduction by 8.3% compared with 2018
HSR share in Railways: 75%
Airplane: Turnover grow by 100% compared with 2018
Rail: Turnover grow by 110% compared with 2018
Airplane intensity reduction by 17% compared with 2018
HSR share in Railways: 83%
Airplane: Turnover grow by 180% compared with 2018
Rail: Turnover grow by 200% compared with 2018
Airplane intensity reduction by 30% compared with 2018
HSR share in railways: 95%
On-road Freight Vehicles
On-road freight share decreases to 43%
Annual truck sales: 4.3 million
NEV market share for medium and heavy trucks : 45%
innovation of hydrogen fuel cells technologies
On-road freight share decreases to 37%
Annual truck sales: 4 million
NEV market share for medium and heavy trucks : 75%
high-pressure hydrogen storage storage and refuelling stations
On-road freight share decreases to 34%
Annual truck sales: 3.5 million
NEV market share for medium and heavy trucks : 85%
Non-road Freight Vehicles
Railway share in freight transport:23%
shipping share in freight transport:35%
innovation of hydrogen fuel cells in shipping transport
Railway share in freight transport:27%
shipping share in freight transport: 38%
Railway share in freight transport:30%

Policies recommended

In general, electric vehicles and plug-in hybrid vehicles will be the main route for the long-term development of China's new energy vehicles. Driven by the "Blue Sky" policies and increasing economic competitiveness, electric vehicles already has the potential to fully replace the light-duty ICE vehicles by 2025 in the fields of taxi/car-hailing services, light freight vehicles, as well as the short-distance commercial vehicles. For private cars, due to lack of economic competitiveness, the promotion of pure electric vehicles will face certain challenges in the next few years, especially after the subsidy is withdrawn. Diversely, continuous incentives (financial and otherwise), improvement of charging facilities, and enhancement of vehicle-grid interaction will be the strong support to ensure the steady growth of the electric vehicle market.

The charging and discharging price are the decisive factors affecting the large-scale application of electric vehicle in the total energy system. According to the current regulations, the only collected fees are the catalogue electricity price (which is lower than the normal electricity price) and a charging service fee. In actual operation, a fixed charging price is always charged. Electric vehicle users have relatively higher price tolerance, and due to the separation of drive time and charging time, there is a high potential to adjust the load for electric vehicle and bring more flexibility to the grid. This is very hard to realize under a fixed charging electricity price. Therefore, it is highly recommended to increase the pace of the research and formulation of the special charging price for electric vehicles, whose design bases itself on local load, which takes into consideration that the charging facility operators should be also entitled to a certain pricing right. For the vehicle-to-Grid (V2G) and the battery-based grid energy storage, recommendations are to design a discharge price to guide the reasonable charging and discharging behaviour of EV owners, with reference to the peak-valley time-of-use (TOU) price.

The transportation and storage of hydrogen fuel, as well as storage infrastructures are the most realistic problems faced by China's fuel cell vehicle industry. Recommendations are:

1. First speed up the industrialization of 70MPa high-pressure hydrogen storage system, reduce O&M costs, and set up clear targets for hydrogen production, storage and refuelling stations.
2. Make operating differential subsidy (ODS) policies for hydrogen infrastructure.
3. Defining the unclear roles and responsibilities between the relevant departments such as housing construction and safety supervision involved in the construction of hydrogen fuel infrastructure;
4. Strengthen the collaborative innovation between hydrogen fuel cells and core technologies of pure electric vehicles such as lithium batteries, motors and motor controllers. Accelerate the research on the coordinated development between hydrogen fuel and pure electric vehicles.

8. Heat sector roadmap

8.1 Summary

Heating sector reforms in China deserve attention due to large energy consumption, low cost options for decarbonization, reducing pollution and high potential for providing flexibility for renewable electricity integration.

The transition from the present heating system towards a more efficient heating system cannot be achieved without incentives created by metering and billing the heat supply, as well as by establishing legislation ensuring that societal objectives are met through organized and comprehensive heat planning for district heating in suitable areas.

The available solutions, technologies and heat sources differ between provinces and climate zones. The planning process should take account of these differences and take advantage of the local opportunities. China should promote either a decentral energy planning methodology or alternatively, replicate the model for planning large infrastructure projects. In either case the planning process requires procedures for finding areas suitable for district heating, procedures for evaluating consumer and socio-economic feasibility, guidelines for choosing technologies, standards and perhaps incentives to deter unwanted solutions and support wanted solutions from the perspectives of economics and flexibility. If no choice is made, such objectives and targets can be difficult to meet.

District heating systems are one of the best energy storage solution for integrating variable power production. District heating can absorb excess power and convert it into heat with high efficiency and fast response time, and low cost compared to electricity storage. Furthermore, power-to-heat and CHP solutions can provide peak load capacity for both power and heating systems integrating the two sectors, creating storage capacity, gaining high efficiency and avoiding curtailment.

The future renewable district heating technologies depends on the implementation of modern district heating network with flow and temperature control, low heat losses, low forward temperature and storage possibilities. The chosen heat planning scheme needs to ensure these solutions are put into place.

Biomass is a limited resource in China and has to be used in efficient solutions. Biomass and municipal waste are then best utilized in CHP plants in connection with industrial parks able to deliver excess heat for heating and cooling of nearby urban areas.

Individual heating is roughly half of the heating demand in the period 2020 to 2050 slightly increasing due to better buildings in urban areas supplied by district heating making the energy share for district heating decreasing. The change in individual area is dominated by phasing out coal boilers replacing them with solar, electricity and gas solutions.

8.2 Introduction

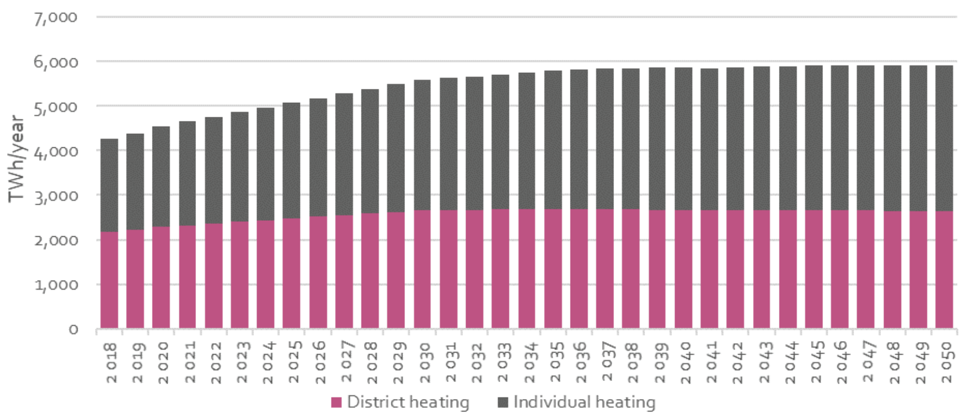
Space heating in China is expected to have a large potential regarding the transition from coal-based fuel to renewable and low polluting energy sources, by establishing district heating and cooling systems capable of using new technologies and resources.

The needed steps in the development of the heating system towards meeting the objectives of the Chinese government can be different in urban and rural areas, and dependent on climate zones and available resources. The development of the heating sector must be able to create solutions fitting to the situation. This chapter discusses the expected heating and cooling development in different parts of China, the second largest sector after industry. Furthermore, the chapter looks into interactions with other energy sectors, energy planning models and the expected future technologies for the heating sector.

8.3 Projected development in heating demand in buildings

The expected heat consumption for buildings according to Figure 8-1 is expected to grow from around 4,500 TWh/year in 2020 to around 5,900 TWh in 2050. After 2035 the consumption will stabilize. The two main drivers of changes in the heat consumption are increase in heated floor area together with a simultaneously change in the building stock towards more energy efficient buildings with a lower heat demand per floor area. The increase in floor area is assumed to follow the initial growth in polulation, together with an increased floor area per capita. The heat demand is the same across the two scenarios and no additional energy conservation efforsts are implemented in the below 2 °C scenario.

Figure 8-1: Annual heat consumption in the heating sector – Stated Policies.

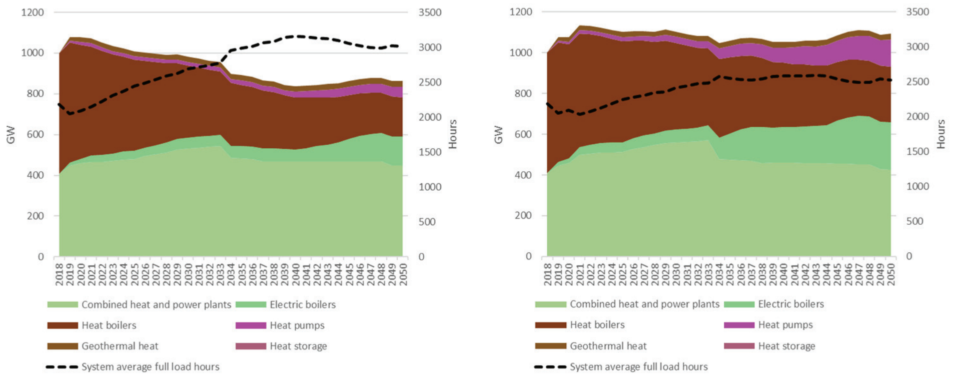


The increase will be largest in individual heating despite urbanization and increasing floor space per inhabitant. With a supply of around 2,300 TWh district heating is responsible for around 50 % of all heating demand in 2020 decreasing to around 45 % in 2050 for Stated Policies scenario and 47 % for Below 2 °C scenario.

The individual heating sector is expected to increase its share of the heat consumption. It supplies a bit below half of the heating demand in 2018, but surpasses district heating and supplies approximately 55% of the heat demand in 2050 in the stated policies scenario and approximately 52% of the heat demand in the Below 2 °C scenario in 2050. One of the drivers for an increase in individual heating share is an increased hot water consumption, which also affects urban areas without district heating supply. The saturation rate of heat demand is also increasing in rural areas leading to a higher demand.

The district heating sector will develop differently dependent on scenario and especially new technologies will develop more in the Below 2 °C scenario, in particular electric boilers, heat pumps and heat storage capacity.

Figure 8-2: District heating capacity development in the Stated Policies scenario (left) and Below 2 °C scenario (right)



The declining capacity in Stated policies scenario and the stable capacity in Below 2 °C scenario both cover an increased efficiency in production and supply of district delivering most in Below 2 °C scenario. The reason for the increased capacity need in the Below 2 °C scenario is only partly due to increased district heating share of the heat demand. The main reason is that the heating sector is used to balance the variable renewable energy in the power sector, leading to an increased need of capacity. This also leads to less full load hours on the production units the Below 2 °C scenario than in the Stated Policies scenario. The increased balancing of the electricity sector is also seen in the decreased production from combined heat and power plants , and increased production from electric boilers and heat pumps compared to the Stated Policies scenario.

Space heating supply is expected to deliver the main energy conservation in the building sector. District heating and better-insulated buildings are key for achieving this.

This demonstrates that heating sector in China is expected to undergo large changes. The sources for heating, as well as the technologies leveraged to provide it, will have to change and district heating will play a key role in the energy transition.

Figure 8-3 and Figure 8-4 show the development of the heating supply by fuel in the Stated Policies scenario and Below 2 °C scenario respectively. The heating supply goes from being almost exclusively fuelled by fossil sources in 2018 to about 1/3 coal , 1/3 electricity and 1/3 other sources in 2050 in the Below 2 °C scenario.

Figure 8-3: 2018-2050 the analysis of heat production by different fuel for SP scenario

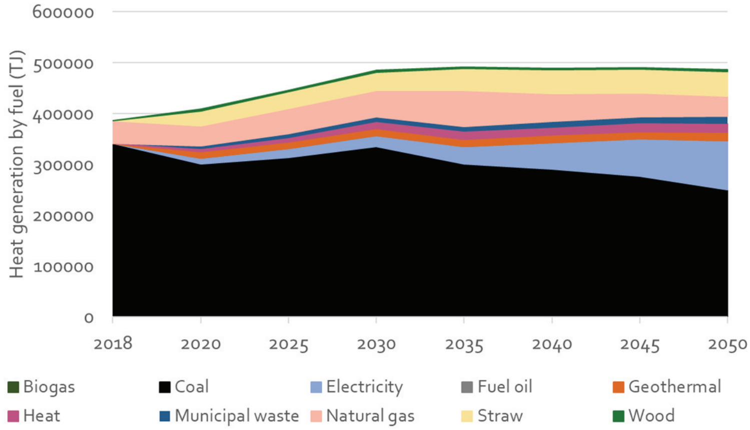
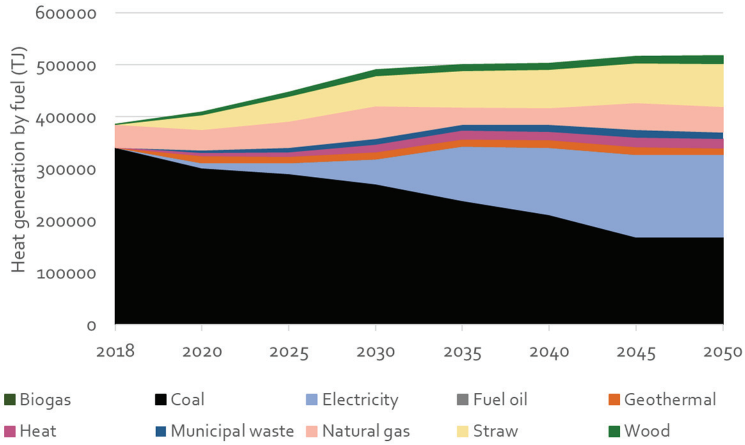


Figure 8-4: 2018-2050 the analysis of heat production by different fuel for B2 scenario



The development of heating supply for individual heating follows similar trends as the district heating sector. Coal and oil is completely phased out. It is to a large extent replaces by heating based on electricity and solar energy, and also gas covers a substantial part of the heating demand. Biomass only covers a small fraction of the heating demand throughout the scenarios.

8.4 Development of the heating system

Provinces in China have different heating needs due to variations in climate and related space heating standard, available heat sources and local conditions of the power system.

The following sections describe some of the expected changes to the heating systems in the different climate zones in China.

Severe cold zones and cold zones

In severe cold zones and cold zones, according to national standard, centrally supplied space heating systems are mandatory installations in urban buildings. The expansion of district heating will continue in large urban areas in cold zones and severe cold zones, replacing coal boilers and individual gas boilers. Specifically, it is expected that most of the large urban areas in cold and severe cold areas will be connected to a district heating system and that domestic hot water will be supplied from district heating. In small rural towns and villages, district heating will slowly emerge based on biomass boilers, solar heating, large heat pumps, seasonal storage and in some cases geothermal heat. The rural development has not yet started and can only be achieved by active and formalised planning, subsidies, and development until suppliers and technologies become cost competitive. Only a part of the small towns and villages in rural areas with well insulated buildings are expected to be converted to district heating on the short term. For rural areas, the development is mainly expected to happen on the long term along with renewal of buildings. Furthermore, in the rural areas domestic hot water will be supplied by individual solar heating panels eventually combined with electricity or district heating.

Hot summer and cold winter zones

In hot summer and cold winter zones, the winter is cold but central space heating is not available according to current national building standard. Space heating demand has increased and will keep increasing in future, how to meet these energy demands is very important. District heating will be implemented in new urban areas if excess heat is available from CHP plants or industry. In some more affluent existing urban areas, which prefer the comfort of district energy systems compared to individual systems, district heating can be expected as well. For new areas, district cooling can be included in the system if excess heat is available. If excess heat is not available, large residential, public, and commercial building structures will be equipped with large heat pump systems supplying central heating and cooling due to both economy and efficiency gains, as well as flexibility advantages compared to individual solutions. The development for areas with hot summers and cold winters is uncertain, and there is the risk that individual heating and cooling prevails in most buildings, if China does not actively plan for the more efficient solutions. If this is to happen, then the overall efficiency and flexibility of the heating and cooling systems will decrease.

Hot summer and warm winter zones

In hot summer and warm winter zones, the present structure of the heating and cooling system can change from individual cooling to district or central cooling depending on the existence of available excess heat sources for absorption chillers in the urban areas. Such a development will be slow and will be dependent on the implementation of a district energy planning legislation, and whether the next generation of CHP plants will have cooling supply included in the set up and suppling heat for local industrial purposes. Present industrial parks with their own heat supply are not capable of supplying cooling to large buildings, due to lack of awareness at the management level and in the government about the possibilities. New legislation and formalized energy planning systems are needed to achieve a higher awareness of the possibilities and to ensure efficient strategies for cooling in these areas.

Domestic hot water is not expected to be supplied by district heating systems in hot summer and warm winter zones. In fact, domestic hot water will mainly be supplied from solar collectors with electricity as back-up, or by electrical boilers. Nevertheless, the need for cooling in summer periods shows the paradox of the individual system, having a chiller emitting heat just beside a solar panel collecting heat for domestic hot water at the same time. Chillers that produce a combination of cooling and domestic hot water could be a promising new technology for the future suitable for areas with hot summers.

Renewable power expansion reduces the contribution of CHP heating

The expansion of solar PV, wind turbines, and other renewable technologies in the power sector will limit the availability of CHP for heating purposes. Scenario results shown in Figure 8-2 shows CHP capacity will fall after year 2032 in both scenarios. Consequently, the district heating systems must increase the heat peak-load production on boilers in order to avoid power curtailment when CHP plants produce less power. However, to limit the high cost heat production on peak-load boilers, district heating systems will increasingly be fitted with meter-based billing systems, flow and temperature control, and day-to-day and/or seasonal storage systems for reducing the heat demand and cut the demand for peak-load. This can be expected in all district heating systems, reducing the energy loss from the present 25 – 30 %, including avoidable loss inside buildings, to 10 – 14 %. This is dependent on awareness of the importance of energy conservation in district heating systems and the implementation of necessary changes in the metering system, the pricing system, and regulation.

Waste-to-energy and decentralized heat sources using excess heat from local sources, including biomass will have increased importance.

New thermal CHP systems

Electricity will be essential for high energy efficiency in new renewable heating system solutions, especially for individual heating, surplus low temperature heat, geothermal heat and air/water heat sources.

In order to avoid fossil peak load production and facilitate the use of inflexible heat sources (i.e. variable renewable power producing when wind is blowing or sun is shining), seasonal heat storage systems can be important for both heat and power systems. Cheap storage for electricity is expected to emerge, but the heat sector will still need storage systems to balance demand and production of heating, which in addition can deliver competitive flexibility to the power sector.

To achieve high efficiency, it is important to consider the localization of CHP plants. If possible, they should be be placed between industrial parks and urban areas with heat/cooling demand, to be able to provide both heat for industry and excess heat for district heating and cooling. Waste incineration, waste and biomass residue gasification, and biomass CHP systems should be preferred over fossil fuel-based CHP production and should replace coal systems. Standards for collecting and handling renewable fuels are necessary, as well as a new legislation and a new subsidy system which can make such heat sources competitive.

New CSP solar technologies producing heat up to 400 ⁰C will probably replace some CHP base load production for industry and/or for district heating in areas with high solar radiation. Such technologies can take over the role of delivering flexible base load supply for heating, cooling and power systems.

8.5 The heating system provides flexibility to balance power systems

Combining capacity on CHP, heat pumps, electrical boilers and heat storage in district energy systems, increases flexibility and efficiency in both the power and the heating sector. District heating systems can be a central solution for balancing the power systems, when combined with other technologies and storage capacity. The following four figures show the scenarios' hourly heating dispatch and it's relationship with the VRE power generation and, more directly, the marginal cost of electricity (the power price). The figures depicted a winter week in 2035 both nationally (Figure 8-5 and Figure 8-6) and in Shandong (Figure 8-6and Figure 8-7), as a selected illustrative province.

Figure 8-5: The marginal electricity cost, VRE generation and the heat generation by technology in China for SP scenario in 2035 winter

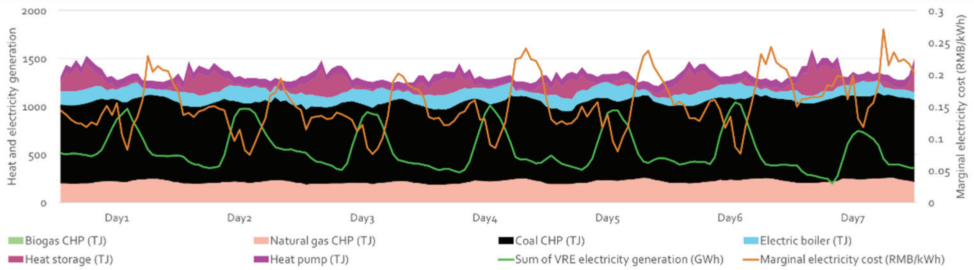


Figure 8-6: The marginal electricity cost, VRE generation and the heat generation by technology in Shandong for SP scenario in 2035 winter

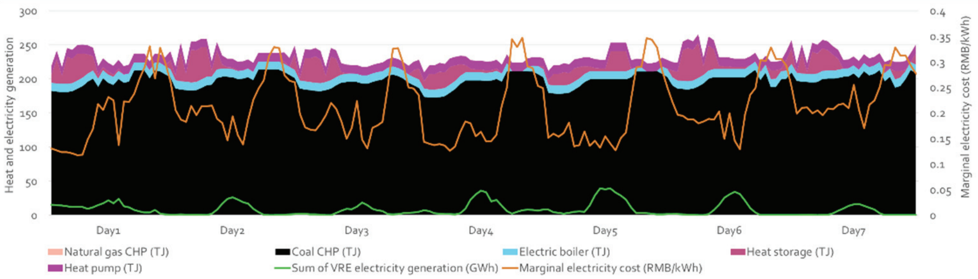


Figure 8-7: The marginal electricity cost, VRE generation and the heat generation by technology in China for B2 scenario in 2035 winter

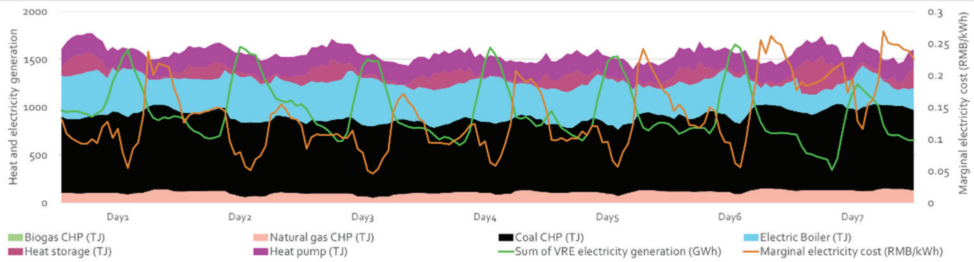
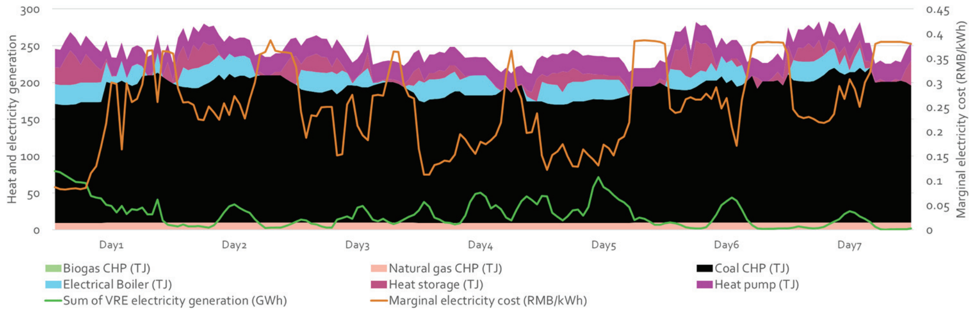


Figure 8-8: The marginal electricity cost, VRE generation and the heat generation by technology in Shandong for B2 scenario in 2035 winter（the colour of Sum of VRE electricity generation, and the colour of electricity cost should keep the same colour with above figures）



In particularly, it can be seen in Figure 8-8 how in Shandong province, there is a strong relationship between heat generated with electric boilers and the power price (marginal electricity cost).

Achieving the maximum benefit from renewable power sources requires the power system to absorb or store variable power when in surplus and inject power back into the grid at times of relative shortage of supply. This will affect the heating system and change it to a system with CHP plants combined with heat pumps, electrical boilers and heat storage, by producing and storing hydrogen for use in CHP production plants. Policy support and/or market incentives must be present to support these solutions to ensure that investments can be recovered.

Market design for integrated systems

When the heat and power sectors are integrated to a higher degree, incentives for both heat and power production must be aligned, to ensure optimally coordinated investment and operation in both systems. If power production is incentivized by high fixed power prices or subsidies, CHP plants will be built with emphasis on power efficiency and inadequate attention to heat supply efficiency. The high electricity prices will cover all the costs for the low efficiency heat production and provide the primary revenue. In case that the heat efficiency increases, the revenues from power sales will decrease due to lower power production caused by the efficient heat production. Consequently, the producer has no incentives in improving the efficiency of the heat production, and society achieves an overall inefficient system. To avoid this, fixed power prices must be set lower than marginal production price in power plants and higher than the marginal power production price in CHP plants. This condition ensures that there is an incentive to produce both heat and electricity in the same plant and makes power-only plants unable to compete in the market. Another example related to the market design of integrated systems consists of the adoption of tariffs or taxes on the consumption of electricity. If the tariff and/or the tax paid per kWh are set at a high level, there will be little incentive in using electrical boilers or heat pumps in the heat system when the power supply is high compared to the demand. Consequently, the optimal interaction between power and heat side may not occur.

These examples show that fixed prices, tariffs and taxes can result in distorted incentives and cause cross-subsidization between sectors.

A market price system for power, fuels, and heat provides the right incentives for integrating the power and heat sectors. Such a price system will induce power producers to optimise their power output to maximise their profit and will support heat producers in optimising scheduling of heat output, particularly if this requires optimising the ratio between electricity as a fuel input versus other heat inputs. Both the power producer and heat producer will stop their production in case of oversupply of heat and power, and the system will give incentives for both heat storage and electricity-based heat production in electric boilers and/or heat pumps.

When producing heat and power in a CHP plant under a market-based system, it can happen that either the power price or the heat price gives the largest incentive for production. Fuel consumption, operation, maintenance and financial costs are normally split between the power and heat side, and it can happen, at certain points in time, that the electricity price is too low for electricity production while the heat price is high enough to produce CHP, although the heat side has to pay for the loss on the power side. In principle, power production should stop its operation, and the plant should continue producing only heat through by-passing the steam for the power turbine, or by using the produced power in an electric boiler. Without such flexibility, the heat side will cross-subsidise the power side, causing a market failure in the power market leading to excessively low power prices, and potentially the curtailment of other power suppliers which are more economical efficient.

The reverse situation can also occur, in which the heating price is too low compared to alternative heating sources while the power price is high. By producing both heat and power, the power side will subsidise the heating side and result in a market failure in the heating market.

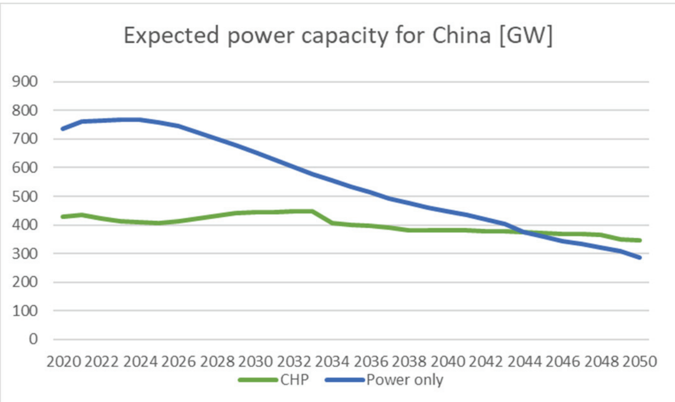
These two examples show that the split of costs between power and heat should be variable and dependent on the relative marginal value of the two goods. Continued power production when power prices are low can lead to curtailment of variable wind and solar plants. Therefore, subsidising power from heat should be disallowed, or at least restricted. The reverse situation, with low heat prices creates problems in the heating market but does not lead to wind and solar curtailment; heat storage systems can resolve the problem by storing heat until periods with higher heat prices.

A market price system for fuel, heating, and electricity will be the best long-term policy for creating incentives for flexible and efficient heating and power systems in China. A market price system can benefit all market participants and would not provide special advantages to specific producers or types of producers. High trading volume and transparency help to avoid participants controlling the market and market pricing.

Flexible CHP plants can maintain revenue

As variable renewable power generation increases, the natural response is to decrease the production in thermal power plants. Relative to CHP, power-only plants are inefficient, and, in the future, CHP plants should be the primary power-producing thermal units. Below, Figure 8-3 shows expected power capacity from modelling stated policies and it is clear the power only production will decrease, and that CHP will remain and adapt to heat demand. The CHP share of total thermal capacity goes from 39 % in 2020 to 55 % in 2050.

Figure 8-9: Projected thermal power capacity (GW)



When the power market dispatch results in fewer hours with sufficiently high electricity prices for thermal production due to cheaper variable renewable production solutions, CHP plants may obtain additional revenue from ramping up heat production relative to power.

Using surplus wind and solar output to produce and store heat can help to reduce power curtailment, especially in presence of high shares of variable renewables. If CHP plants additionally stop power production when prices are low and use the existing infrastructure to consume electricity in an electrical boiler or heat pump, they can absorb excess electricity creating a flexible energy system. Flexible CHP plants are in this way able to provide the same balancing services to the power system as pumped hydropower or batteries without the need for additional cables and will be able to maintain revenue.

District heating is a source of flexible electricity demand

Flexibility in the electricity system can be achieved by replacing fuel consuming equipment with power consuming equipment. However, this solution will only increase the flexibility in the system if the equipment can operate according to the electricity production from renewables. Otherwise, it will just constitute an increase in electricity demand. District heating systems with several different heat sources and heat storage capacity can provide flexible electricity demand by increasing and decreasing the power consumption depending on the power market price.

Green fuels can integrate with district heating supply

Surplus power from variable production can be used for producing green fuels, like hydrogen and methane. This production generates heat which is useful for heating in district heating systems. The feasibility of the conversion of power to green fuels depends on the surplus power and the low power prices being present many hours annually. This approach might also require additional improvements regarding the framework conditions in the market system and support from subsidy, tax and tariff systems. This is not the current situation in China yet; however, if the production of green fuels becomes widespread, it can create increased flexibility for the power system and deliver an additional heat source to the district heating. In the Stated policies scenario, 178 TWh hydrogen and biofuels is produced in 2050. In the Below 2 °C scenario, 485 TWh is produced. A share of this can be expected additional heat source.

8.6 Energy planning

This section discusses how authorities can facilitate the before mentioned development as well as the need for legislative changes. The authorities will have to rethink the structure of the energy sector and establish a formalized heat and cooling planning legislation ensuring efficient, flexible, and competitive solutions for residential, public, and commercial district energy supply, including industrial heat supply.

For achieving the projected development, a power market must be in operation, heat/cooling consumption must be metered and billed according to supply and tax/subsidy and tariff systems supporting it. Then, the basic incentives for renewable and efficient energy saving solutions will be in place. Today, much of the development and planning does not integrate power, heat, cooling, industry and gas systems. Solutions often optimize only parts of systems, creating curtailment and surplus in other parts. Integrated energy planning is essential for meeting the coming objectives for society and the energy systems.

There are different ways to plan for the future system with the pros and cons depending on the chosenmethods. The key priority for the next five year plan is to decide a planning model .

Pure market-based approaches may not support overall societal objectives

In some western countries, 100% market-based solutions are preferred for the development of the energy system, with the expectation that the market adapts to overcome any issues and ensures that production always meets demand. This may be true regarding short-term prices for building developers, but not for other actors, and especially not when public objectives need to be met. There is a risk that developers will save on short-term investments leading to a higher cost in reinvestments in the long-term. This is likely to result in higher variable energy prices for the consumers. A 100% market-based system will then not meet public objectives.

Centralised energy planning features consistency but risks not accounting for local conditions and ownership

The planning system can be centralised if authorities' direct specific provinces, towns and district on which actions to execute for meeting the objectives. The authorities require central specialists, advisors and perhaps universities to carry out the planning of the energy system. Consequently, most of the knowledge will stay in such central institutions: local authorities will have little ownership of the projects except for the subsidies and revenue received as a result of the centralised planning. The authorities will have to ensure financing by assisting the provinces and towns with grants and subsidies for solutions that make them competitive. The present 26+2 heat planning project[222] in China is an example of centralised heat system planning. The advantage is that the planning and implementation of required changes can be done at speed, however, the changes will only occur in the selected areas without taking advantage of the possible contribution of other areas of the country towards achieving the public objectives.

Decentral energy planning supports local engagement, but must be supported by centralised framework

In a decentralised planning model, the development of the energy system will be decided by local authorities, while the central government will set a legislation framework to ensure that the local governments follow the national objectives. For example, an air quality standard can be set by central authorities, however, local authorities need to define their own way to meet such a standard. The local authorities can propose a planning system that suits the local context; therefore, different areas can follow different plans accounting for different local solutions dependent on their possibilities. This way of planning is similar to the model used in the European Union, making the independent countries responsible for finding own solutions and planning models to fulfil common targets and standards. The advantage is that knowledge will be achieved locally and that local authorities will take ownership to targets and changes. Meanwhile, central authorities must only focus on targets, the legislative framework, reporting, and control system.

This system requests local legislation, and as a consequence, the planning models used in the provinces varies from province to province. Such a setting might lead to the risk that targets are not met if provinces have different priorities or if the needed knowledge, technologies, and heat sources are not available, expensive or difficult to achieve. Central authorities may have to establish different targets for specific provinces and might have to facilitate the financing of projects.

China evidently does not have the same structure as the European Union, and this has an influence on how the energy planning model is established, by fitting to the structural and political system. Decentralised planning may be a suitable model; however, China will need to find its own version of the model in a manner fitting to the present economic and political structure while making the provinces responsible for meeting individual objectives dependent on local possibilities and the level of the local economy.

China's existing infrastructure planning approach could support system planning for heating and cooling

In recent years, China has shown a strong infrastructure planning model regarding the construction of highways, railways, airports, telecommunication systems, among others. Building infrastructure for efficient, flexible and renewable district heating and cooling is not different from building other types of infrastructure, and China has an excellent class model for doing so in a fast and efficient manner. If China applies the model used for other infrastructure to for district heating and cooling, such a planning should include a formalised model for finding areas suitable for heating and cooling, a model for evaluating consumer feasibility and socio-economic feasibility and a model for establishing local network companies and financing.

If the infrastructure planning approach is applied for the heating and cooling system planning for China, the difficult part will be finding energy sources for the urban areas suitable for district heating or cooling. Excess heat from CHP plants and industry will be the most appropriate source, although it should be replaced with renewable sources in a longer perspective. It is difficult to see how the needed investigations in heat sources and establishing local heat production can be achieved without including local knowledge in the planning process. It might still be a job for the local authorities to find, organise and deliver heat and cooling to established networks. The advantage of such a system is the possibility to define a low loss network standard including flow and temperature control and professional network construction and centralised planning combined with local knowledge on the available heat sources.

The heat and cooling production and delivery may or may not be included in the network company and the planning system. If not, the system will be unbundled with third party access which demand rules, standards and legislation for making non-discriminating agreements with suppliers, contracts and payment systems and probably some kind of public price control in the form of benchmark or price cap.

This way of planning district energy infrastructure can be a good solution, however, if the planning system and solutions do not integrate industry supply and demand, power system, waste management, renewables and other local opportunities it can potentially miss some of the advantages of energy systems integration.

8.7 New technologies play a critical role in the future of district heating and must be demonstrated

The changes in the power sector, the development of heating sectors and the need for energy planning will lead to changes and new technologies is expected to play a critical role for promoting an efficient, dynamic and diversified energy system, which relates to the previous sections on what can be achieved with district heating.

Heat storage, solar heat, geothermal heat, large district heating heat/cooling pumps using low temperature heat sources, small and big biomass solutions, gasification solutions, waste incineration, excess heat from industry and a new generation of district heating and cooling systems will be some of the most important technologies for heating and cooling in the future. These sources and technologies have different characteristics and may need further development and support in a future energy system. Coal and natural gas CHP will decrease their operation in the future. Coal and natural gas technologies are not discussed in detail in the following section; however, such technologies have a potential for increased efficiency and will in combination with other technologies still be part of the future heating systems. Figure 8-3 and 8-4 show that fossil fuels slowly will decrease towards 2050, but still be around 50 % of the sources in the Stated Policies scenario and around 40 % in the Below 2 °C scenario. There will be a change from coal to natural gas making natural gas increasing until 2030 and 2040 dependent on scenario. It then will be important to set standards for new natural gas equipment for increased efficiency and reduced emissions.

Individual technologies will still be a large part of China's heating and cooling. Figure 8-1 show how these technologies will have increased efficiency due to technology development and also by minimum standards set by government.

Future district heating and cooling systems

District heating and cooling systems have comparative advantages to individual solutions with respect to efficiency, economics and flexibility. These relative benefits fade if the district heating distribution system is inefficient through heat losses. The district heating transmission and distribution technologies and supply conditions also needs to be improved.

To achieve the highest degree of flexibility and efficiency from district heating systems in the future it is recommended to develop them towards the concept of 4th generation district heating. The 4th generation distict heating is a coherent technological and institutional concept, which by means of smart thermal grids assist the development of sustainable energy systems[223]. It involves operating the district heating system at low temperatures to reduce the losses and enable a large variety of production sources, including low temperature surplus heat and renewable sources such as geothermal and solar heating. It also means that the district heating system is able to be an integrated part of the overall energy system, thereby helping to integrate fluctuating renewable energy sources in for example the electricity mix. Furthermore, it involves ensuring a suitable planning, cost and incentive structure in relation to operation as well as strategic investments.

Losses in current Chinese district heating transmission and distribution systems are often unknown. Frequently, substations are constructed for several buildings and the measured delivery point for the district heating is at the substation. Therefore, the heat loss data cannot be directly compared with other countries' who meter supply at building or household level. A common estimate is that district heating losses in China are 30 % of the produced energy, but his represents not only the loss in the piping network, but also the loss inside the buildings, due to too high temperatures and unnecessary energy consumption. A standard Chinese district heating system does not contain flow and temperature control and has obsolete substations. Table 8-1 shows expected loss in Chinese systems according to the design and system control level.

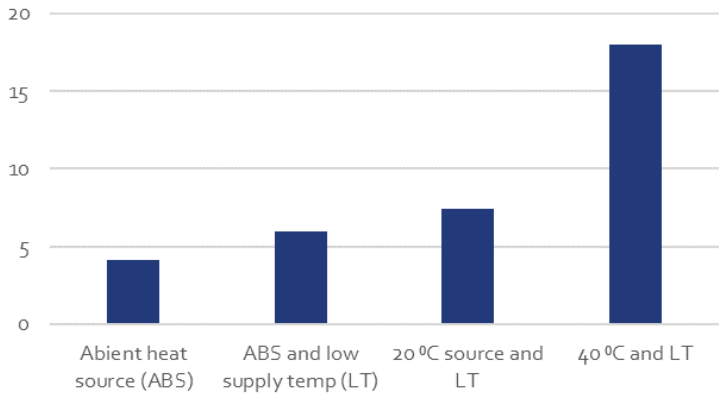
Table 8-1: Heat loss in distribution network[224]

	Reduction	Loss	Supply situation
Heat loss 1'st level		30.0 %	Present system – no metering flow, and temperature control at substations and inside apartments
Heat loss 2'nd level	20 %	24.0 %	Automatic control at substations
Heat loss 3'rd level	15 %	20.4 %	Temperature control radiators and/or floor heating
Heat loss 4'th level	15 %	17.3 %	Direct supply – substations removed. Individual metering.
Heat loss 5'th level	5 %	16.5 %	Supply temperature control according to outdoor temperature

The reduction in losses can result in lower forward and return temperatures, making heat pumps, solar collectors, geothermal systems, boilers, and CHP systems more efficient. The change in the district heating control and metering system is crucial for being able to collect renewable heat sources with most of the new technologies described above.

For heat pumps, the efficiency increases dramatically if the supply temperature to the buildings can be reduced to a low level around 60 ⁰C according to the examples in Figure 8-10.

Figure 8-10: Heat pump COP of expected 2050 technologies with different sources and low supply temperature[225]



In the examples in Figure 8-10, the efficiency of the same heat pump is simulated by different heat source temperatures and different supply temperatures. The efficiency (COP=Coefficient of performance) goes from 400% to 600% when the supply temperature is reduced from present 90 ⁰C to 60 ⁰C. It further increases to 740% if the heat source of 20 ⁰C is available instead of normal ambient sources (10 ⁰C). Finally, it increases to 1800 % when a 40 ⁰C heat source is available. This calculation shows how important the new generation of district heating network will be in future when heat sources for floor heating are going to be the dominated by low temperature renewable heat source like geothermal, solar collectors, combined heat and cooling production and low temperature excess heat from industrial production.

To establish incentives for building this kind of district heating system metering and billing according to energy supply is required.

Increasing heat storage is critical for flexibility and optimising asset utilisation

Only few examples of heat storage systems have been demonstrated in large scale in Asia including in China. Some experiences with steel tanks for daily storage can also be found in China. Renewable heat from solar sources, geothermal, excess electricity and intermediate industrial heat sources calls for heat storage systems to increase the overall efficiency and flexibility in future. In Denmark, the benefits of heat storage have been demonstrated by increased efficiency, higher flexibility and saved O&M costs. Heat storage systems are expected to be pivotal in future heating and energy systems.

For China, the investment costs in storage systems are still too high according to a demonstration project in Tongchuan, Shaanxi province, which can be decreased with the introduction of more competition between suppliers. More demonstration projects can be a way to support the implementation of heat storage in China. This calls for more demonstration projects in next two five-year plans.

Solar heating can be exploited in new ways in China

China has extensive experience in producing solar collectors that cover the hot water demand of single-family houses and industry users, however, it only has few successful experiences in solar heating for district heating. Experiences from Denmark show a large potential in solar district heating systems. When combined with daily and seasonal heat storage systems, solar district heating systems can produce base load heat and reduce consumption of fossil fuels. Furthermore, China has high solar irradiance during summer and winter in large parts of the country and it is expected that solar heating will be an important heat source, especially for rural towns and villages. The first solar heat plants have already been developed and it is expected that investment prices will decrease due to more suppliers, increased experience and improved competition.

Efficient solar heating depends on the development of storage systems, 4^{th} generation district heating systems with low forward temperatures, and to some extent large heat pumps able to increase efficiency in collectors and storage systems. Solar collectors can utilise approximately 40 % of the solar irradiance, which is double the performance of photovoltaics.

New solar collectors combined with PV can increase the efficiency for both PV and heat collector systems. New CSP solar heating technologies, able to produce heat in temperatures up to 400 ⁰C may be a new catalyser for solar systems for producing heating, cooling and power.

Solar heating in large scale district heating system is not mature in China and more demonstration projects are needed.

Geothermal heat

Geothermal heat covers several heat sources; hot springs in the surface of the earth, rock heat, ground water heat, to deep ground heat from dwellings 1-4 km underneath the surface of the earth. The temperature levels may differ from 10 ⁰C to more than 100 ⁰C and, dependent on temperatures and setup, heat pumps are often needed to efficiently utilise the heat source and capture all the energy. Underground geothermal heat normally has quite expensive initial investment and low operation cost, which depend on the electricity price., and can be an important heat source for the future in China in areas with available sources.

It must be developed, and potentially subsidised dependent on the power price for electricity needed for pumping and heat pumps. The present power price system in China might not accommodate the needs of geothermal heat solutions and further investigation into the cost of electricity for geothermal heat is needed. More demonstration projects are needed.

Large heat pumps for heating/cooling

Large heat pumps for heating and cooling are needed to produce efficient cooling and heating energy from renewable sources like solar heat, geothermal heat, waste water, excess heat industry, air, lake/sea/rivers, excess electricity from power system or the like. Heat pumps are extremely important for collecting low temperature renewable heat sources and reusing the energy in district heating systems. Large heat pumps are one of the most important key technologies for making the transition from fossil fuels to renewable energy possible. Heat pumps can be driven both by steam (hot water) in absorption heat pumps, and by electricity in compressor heat pumps. Both types of heat pumps can additionally be driven by gas using a burner in absorption heat pumps and an engine for compressor heat pumps.

The large electric heat pumps is expected to cover 7.4% of the district heating heat demand by stated policie scenario and 18.3% in the Below 2 °C scenario. This tells that large heat pumps can be important if high climate targets are set in China.

The heat source temperature and heat supply temperature define the efficiency of the system, making the heat production cost dependent on high temperature sources and low supply temperatures. A new generation of district heating systems are essential for the efficiency of heat pumps, since they operate at low temperatures, and therefore allow for lower temperature sources for the heat pumps.

Heat pumps will probably be used locally for producing heat where sources are available and will reverse the district heating system from central heat deliveries to locally produced sources. This transition will not be limited to small urban areas but can also take place locally in large urban areas using excess heat from all available heat sources.

The present power price system is not suitable for heat pumps needing a lower price in general and incentives for producing in periods with low electricity demand and/or high electricity supply.

Heat pumps will be important for individual heating covering 22.5 % in the Stated Policies scenario and 27.9 % in the Below 2 °C scenario.

Small- and large-scale biomass solutions

Biomass resources are limited, and only a fraction of China's fossil energy use can be replaced by biomass. Biomass should be used where it provides the largest value, for example as fuels for transportation or for producing raw material for the chemical industry. Alternatively, biomass should be used where it gives largest reduction in climate effect as fuel in industrial CHP plants replacing coal or coal boilers.

In China, biomass collecting, handling and transportation is neither standardized nor automated at present. Moreover, it is challenging to harvest, collect and transport over long distances for most biomass types. Standardization is important for machine builders, transportation vehicles, boilers, and handling equipment providers. Without standardization, costs for equipment will be high and solutions will be inefficient.

China's biomass resource is predominantly agricultural residues. Wood products are limited but may increase in the future according to the reforestation plans in many provinces of China. At some point new forest yields will be used in building materials and the residues from managing the wood and the residues from building industry will be possible energy sources for the industry and heating sector.

Currently, agricultural biomass residues do not have significant value for farmers and are often unused. This leaves farmers with a problem, since it is not allowed to burn the biomass on the fields. Biomass residues need to have a value for farmers, giving them incentives for collecting and selling the biomass for revenue.

The present situation calls for a two-stage development. The first stage is about standardizing the collection, transportation and handling system; and using the residues in local industrial areas, local towns, and villages in CHP plants and boilers. The second stage is about gasification and making biofuels for transportation and industry, or letting the biomass be a part of industrial processes making biological raw materials for products. In other words, the first stage provides the infrastructure, while the second stage increases the value of biomass across the entire supply chain.

Without national waste gas emission standard for biomass boilers, there is ambiguity on whether biomass heating is clean or not. Chinese authorities need to develop and issue national standards and solutions, in order to clarify its clean energy proposition and support its sustainable development.

Gasification provides a means to utilise waste water and biological residues as energy resources

Gasification is a process that is growing worldwide. It is primarily manure from animals and waste water treatment sludge that are used together with animal and biological residues. Biogas processes improve the fertilizing value of sludge and provide storable gaseous fuel important for future transportation and industry. Gasification of biomass residues and wood are emerging technologies still in demonstration.

Compared to the direct incineration in CHP plants, gasification has additional losses. Consequently, gasification has primarily been used on wet manure and sludge not suitable for incineration. However, the environmental benefits from gasification compared to incineration may soon make gasification more relevant than incineration and change the technology choice from incineration to gasification.

Gasification of wood and other residues is not without challenges and the technology still needs to be improved, investment costs are currently high and often needs subsidies. More demonstration projects are needed.

Waste-to-energy plants can supply urban heating, industrial energy demand and supply electricity

Waste incineration has a significant positive CO_2-effect compared to landfilling and should be implemented in all urban areas of China, and with the energy used for industry, heat and power. Proper cleaning of the flue gas is vital for a positive environmental impact of waste incineration. Industry using heat and power all year round is the optimal partner for waste incineration and waste incineration plants should be placed in industrial areas having priority to supply heat and power to the industry. District heating and cooling systems may be connected to industry areas, collecting excess heat from the industry and waste incineration plants, optimizing the overall efficiency.

Waste should always be sorted for valuable raw materials like metals, plastic, paper, glass etc. before incinerated. Waste incineration should always be the last solution and only if it is not possible to sort for reuse.

Gasification may prove a better treatment process in the future compared to waste incineration. It should be possible to utilize more of the available energy in the waste with gasification, but the technology is currently less mature. However, this does not change the fact that waste should be treated in a way where it is possible to harvest the available energy.

9. Power system development

9.1 Main findings

Electrification in the end use sectors boosts the electricity consumption. The energy transition requires a high penetration of renewable energy in power sector.

Electrification is one of the key elements in the energy transition. It provides not only space for efficiency improvements on the end use of energy, but also big potential on electricity supplied by renewable energy that can significantly accelerate energy transition. According to Below 2 °C Scenario, the electrification rate grows from 26% in 2018 to 47% in 2035 and 63% in 2050. The electricity consumption in 2050 is more than doubled compared with the 2018 level. It is mainly driven by the transport and agriculture sectors and increasing applications of hydrogen produced from electricity.

Renewable power technologies are the most promising and mature technologies that can efficiently and cost-effectively reduce CO2 emissions in the energy sector. Along with a growing electricity consumption, it is essential for power sector to provide clean energy by integrating a high penetration of renewable energy. Our results show that in the Below 2 °C Scenario, the share of renewable energy generation in power sector increases from 27% in 2018 to 73% in 2035 and to 87% in 2050. Renewable energy in the power sector contributes to 64% of overall renewable energy consumption in 2018, 77% in 2035 and 81% in 2050 respectively. More than 50% of conversion losses in 2018 is reduced through integrating renewable energy in power sector during the period of 2018 to 2050.

An energy transition driven by renewables requires a reimagining of China's power system.

To adopt renewable power generation in power system, the integration becomes critical, as renewable generation is fluctuant, distributed and uncertain. The scenarios demonstrate that while the post-transition power system outperforms the present system according to all relevant criteria, the system is radically different. Characteristics in terms of asset mix, dispatchability, operational paradigm, cost structure, operational timescales, and topology, will transform. The system cannot be planned or operated according to today's principles, using today's sources of flexibility, under today's regulatory paradigms. Every aspect of the power industry needs to be ready to be changed itself, from market designs and regulatory setups, to product and service definitions, to stakeholder roles. Power system planning, innovation, and reform must be forward-looking. Managing uncertainty, variability, and complexity will be key.

To accommodate high penetration of renewable sources, China's electricity market should be able to mobilize existing flexibility through efficient price signals and market services, as well as to guide investments in unavailable flexibility sources through long-term market design. The power system should be structured to efficiently dispatch available flexibility such that fluctuations and uncertainties can be handled without interfering the system security.

Renewable energy is competitive on cost basis, on value adjusted basis, and in the long run can reach high penetration levels if cost-effective flexibility is deployed.

Based on recent years' experiences, it is projected that renewable energy costs will continue to decline, making wind and solar competitive with investing in new coal power plants during the 14th Five-Year Plan period. When the external costs of coal power plants are accounted for, investments in new renewable energy sources will be cheaper than continuing to operate existing coal plants. The focus on cost reduction of onshore wind and solar PV will be shifted from reducing equipment and construction cost to improving the capacity factor.

The power reforms and meaningful carbon price levels will take some time to implement. The scenario results suggest that until 2040, carbon market is a very efficient tool to make non-fossil fuel competitive with fossil fuel, which indicate that the additional system integration cost by renewable energy still needs stimulations through policies. The price of CO_2 should translate to a higher market value for renewables and a disincentive for fossil-fired generation as a (partial) proxy for the external costs from fossil fuel combustion. Auctioning of CO_2 allowances could finance accelerated investments in the energy transition.

Role of natural gas and carbon capture and storage in future power system.

Replacement of coal with natural gas will reduce CO_2 emission from the power sector. However, natural gas based power production is expensive relative to cleaner technologies for providing coal-replaced electricity as well as power system balancing. Its growth in power system is mainly driven by forced policy targets (e.g., Energy Supply and Demand Revolution (2016-2030)). We anticipate China's energy transition will involve a leapfrogging of gas-based power for economic as well as environmental reasons.

Carbon capture and storage is an alternative solution for CO_2 emission reduction. There are 18 large-scale CCUS facilities operating globally, and only 8.2% of the captured CO_2 is from power sector, due to high cost and other cost-effective CO_2 reduction solutions. The scenario results show that CCS is not competitive with other reduction solutions unless a very high carbon price or very strict CO_2 budget is set for power sector. As the cost of renewable energy as well as chemical battery drops significantly, "RE + storage" will be more attractive than "Coal + CCS" from an economic and environmental point of view.

In the 14th Five-Year Plan period (2021-2025), China should set clear guidance for developing the power sector.

Integrated long-term planning of generation, transmission, as well as flexible sources (such as storage, flexible load, etc.) is extremely important. Given boundary conditions, such as national targets of non-fossil fuel energy and electricity consumption growth predictions, a proper planning model and a standard planning procedure can help to evaluate and coordinate the development of infrastructure, power sources, and flexibility investments. With a clear long-term vision, potential risks and uncertainties can be examined through the model, thus is reduced by improving the policy framework. By fitting into the long-term strategy, short-term targets can better facilitate the long-term visions to yearly action plans without impacts from short-term incidents.

Clear capacity targets for renewable power development. While the cost of wind power and photovoltaic keeps decreasing in 14-FYP period, the development of some technologies, such as offshore wind power and CSP, still depend on subsidies from the government. It is important to maintain annual additional capacity targets for the projects, so that a level of industrial scale of equipment suppliers and construction ability can be maintained while the total amount of subsidy can be limited to an affordable level.

Flexibility is an essential element for the successful integration of renewable energy in power system. Therefore, it is important that the policy design is able to promote flexibility in power system. On one hand, a market should be established to facilitate the flexibility services so that the existing flexible sources can be discovered and better utilized. On the other hand, the reservation of flexible sources in the system should be established to attract investments on flexibility and to maintain a stable level of flexible capacity.

Consistent policy framework is important for a smooth energy transition. Even though the subsidy for onshore wind power and photovoltaic power will phase out in 14-FYP, new mechanisms and regulations are necessary to continue to drive the cost reduction, by improving investment and utilization environment as well as enhancing regulations and monitoring system. Policies for fossil-fuel plants need to be established, so that insufficient operating hours can be compensated for providing flexibility and a smooth phase-out of inefficient and unclean plants. Considering not just from the energy supply's point of view, but also from the industry development and diversity, it is also important to continue the support of other kinds of renewable energy than wind and PV, such as biomass, CSP, geothermal, marine, as well as related technologies in battery storage, hydrogen, etc.

Continue to foster a good market environment for renewable integration. Continue to complete and consolidate existing spot markets and focus on mobilizing flexible sources in current power system to better integrate renewable energy, such as transmission capacity, thermal and hydro power plants, industrial demand response and storage. Better utilize the Mandatory Renewable Electricity Consumption Mechanism[226] to ensure the renewable share in electricity consumption and to promote the willingness to consume green energy. Enhance the national carbon market and expand the quota coverage to reflect the external cost of emissions. Establish an effective administrative monitoring system during the power sector reform process to maintain the market rules.

Adding new coal power capacity should be avoided. Adding new coal power capacity with a lifetime of around 40 years would be contra-productive for the energy transition, introducing risks for stranded investments in a competitive power market and could turn out to be less cost-competitive compared with the best renewable energy solutions. Hence, investments in new coal capacity should be avoided or limited as much as possible. In addition, the institutional mechanisms for accelerating a smooth retirement of old and inefficient coal plant needs to be put in place. Limiting the share of coal in the electricity generation mix is critical for the reduction CO2 emission and structural enhancement of power supply, especially during 14-FYP, when the cost of renewable energy is still higher than coal and the impacts of carbon price is weak.

9.2 Power consumption development

China sees a steady growth of electricity consumption throughout the 2018-2050 period. On one hand, it is to support the economic growth and enriched needs for high quality life. On the other hand, it is driven by electrification of all end-user sectors to achieve a more efficient and clean energy system. Electricity saved through improvements of efficiency will also affects the electricity demand. This leads to slower growth of electricity consumption in later stages.

The total electricity consumption shows increasing trends in both scenarios, corresponding with the continuous electrification in China. In Stated Policy Scenario, the total power consumption increases 1816TWh in 2025 and 3726TWh in 2035 compared to the power consumption in 2018, and the increment in 2050 is 5613TWh, which almost is equivalent to the total power consumption in 2018. The Below 2 °C Scenario has a faster increase compared to Stated Policy Scenario, and the difference between two scenarios will reach 1,543TWh in 2035 and 2,222TWh in 2050, 19% of total power consumption in the Stated Policy Scenario in 2050.

Table 9-1: Electricity consumption composition by sector (TWh)

Scenario	2020	Stated Policy			Below 2℃		
Year		2025	2035	2050	2025	2035	2050
Agriculture	124	162	243	345	175	290	459
Construction	78	91	121	151	92	123	169
Industry	4246	4546	4902	5099	4594	4990	5153
Transport	112	228	622	1332	252	794	1488
Buildings	2227	2754	3603	4339	2806	3991	5120
Hydrogen production	0	133	333	445	473	1180	1543
Total final consumption	**6787**	**7914**	**9824**	**11711**	**8391**	**11367**	**13933**

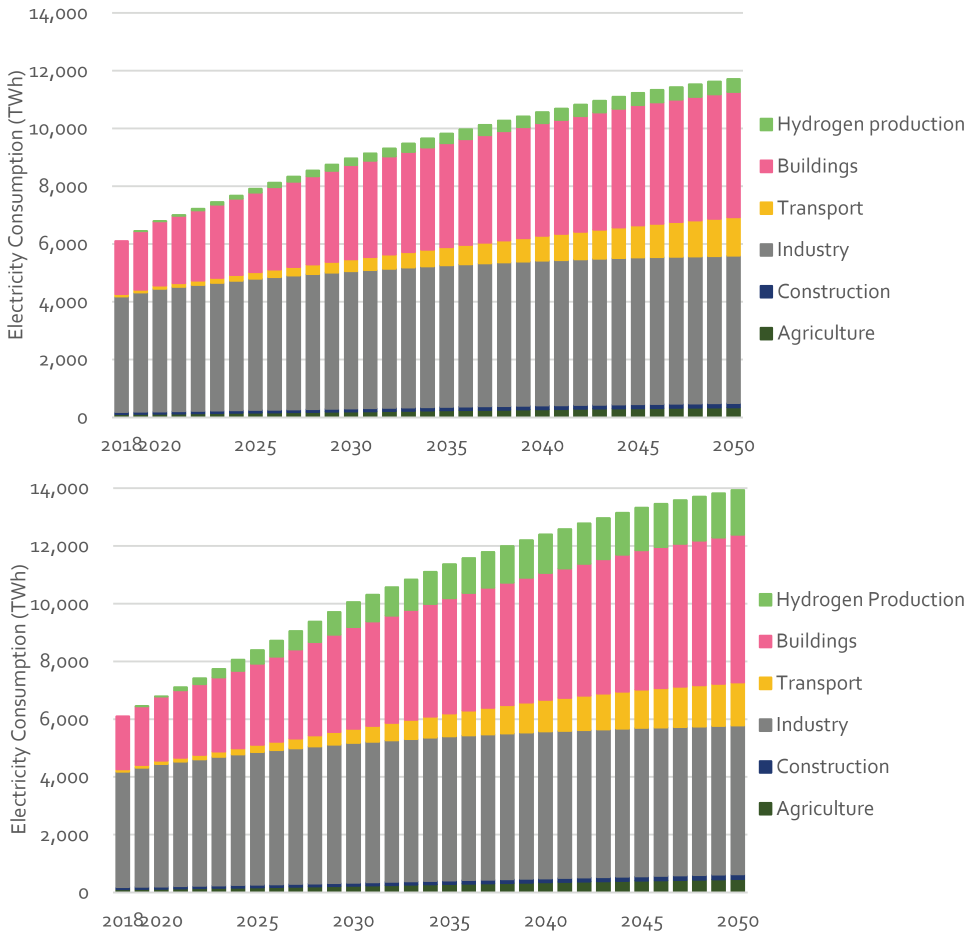
Structural changes in power consumption mix

Currently, the industrial sector has the largest share in the overall power consumption. As China has reached the middle or late stage of industrialisation, many heavy industries have reached their peak. It is expected a rapid transition from low-end manufacturing and heavy industry to urban industrials and high-value services. The power consumption in industries has no growth potential due to the improvement of electricity efficiency and the decline of industry share of the Chinese economy.

The significant power consumption growth happens in the transport sector, hydrogen production and building sector. To support the development of Information industry, more data centres are expected to be placed in China to handle the massive amount of data. The need for data imposes more electricity demand in building sector. Similarly, due to the increasing numbers of electric vehicles (EV), the electricity demand in transport sector sees a dramatic growth. Both scenarios assume increasing uptake of hydrogen, especially for industry. Hydrogen could be used as the reducing agent to replace coking coal for crude steel, and also to produce ammonia, replacing current coal-based synthetic ammonia production technologies. In addition, hydrogen has a potential in replacing oil products in transport sector.

In the Below 2 °C Scenario, the power consumption in the transport sector in 2025 achieves 3 times compared to 2018, 9.5 times in 2035, and 17.8 times in 2050. The hydrogen production consumes 1180TWh in 2035, 10% of total power consumption. Buildings consumes 3991 TWh in 2035, more than twice as much as 2018.

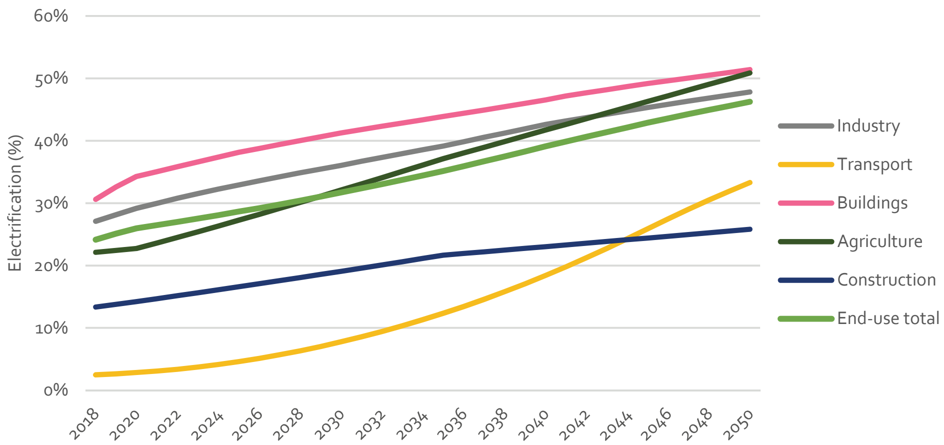
Figure 9-1: Electricity consumption in China by sector from 2018 to 2050 in the Stated Policy Scenario (top) and Below 2 °C Scenario (bottom)



Electrification in different end-use sectors

China is expected to see a continuous electrification in all sectors, and the electrification rate of the total end use consumption will increase about twice, from 24% in 2018, 35% in 2035 to 46% in 2050.

Figure 9-2: Electrification progress of various sectors in the Stated Policies Scenario



In the industrial sector, applications of electric arc furnaces (EAF) will dominate the production of steel, by phasing out blast furnaces in steel production and by increasing the scrap steel recycling system. It is assumed EAF steel produced from scrap accounts for 65% of steel production in 2050.

With regards to heating applications, other than replacement of fossil fuel by hydrogen and biomass, the utilization of heat pumps in district heating and low temperature industrial heating is also important. Such replacement contributes to higher electrification in industrial and building sector.

In the transport sector, it is assumed to ban sales of fossil fuel cars by 2050 in the Stated Policies Scenario and by 2035 in the Below 2 °C Scenario. We project EV adoption trends continue to accelerate, such that by 2030 BEV sales constitute 50% of total passenger vehicle sales in the Below 2 °C Scenario. We project that by 2028 EVs will surpass combustion engine vehicles in annual sales, and by 2050, BEVs account for more than 92% of new passenger vehicle sales.

In the period from 2018 to 2050, the building sector has the highest degree of electrification, and increases from 31% to 51%. Industry and agriculture also have a high electrification degree: industry sector sees an increase of electrification rate from 27% to 48%, agriculture sector sees the increase from 22% to 51%. Transport sector has the fastest electrification, increasing about 16 times from only 2% in 2018 to 33% in 2050, while construction sector increases electrification degree most slowly, only doubling from 13% in 2018 to 26% in 2050.

9.3 Power generation and capacity mix

To support the growth of electricity demand and to accelerate the energy transition, China's power supply sees a significant trend on integrating renewable energy to replace fossil fuel especially coal. In 14th Five-Year Plan period, onshore wind power and photovoltaic will take the lead to be cost competitive with coal power. Renewable power will be the major source to substitute incremental electricity consumption, and the investments in renewable capacity dominates the new installations. After 2025, still led by wind power and photovoltaic, renewable power will play an even stronger role in power sector. As addressed in previous studies and confirmed in the research this year, wind and solar will become the backbone of power system before 2035 in terms of both capacity share and generation share, and coal will change its role in system operation dramatically.

Table 9-2: Scale of installed capacities and key indicators

Scenario	2020	Stated Policies			Below 2℃		
Year		2025	2035	2050	2025	2035	2050
Total Capacity (GW)	**2053**	**2539**	**4027**	**5395**	**2717**	**5124**	**6730**
Coal	1023	950	691	420	1037	730	445
Oil	2	1	0	0	1	0	0
Natural gas	104	165	263	214	132	197	152
Nuclear	53	70	95	110	66	87	100
Total RE Capacity (GW)	**870**	**1352**	**2979**	**4651**	**1482**	**4110**	**6033**
Hydro	347	386	455	533	347	386	455
Wind	242	425	1121	1922	507	1,763	2,636
Solar	246	485	1346	2135	536	1,836	2,803
Bio	35	56	55	57	51	54	55
Geothermal	0.06	0.1	0.45	2	0.12	0.60	5.00
Ocean	0.05	0.28	0.88	2	0.28	0.87	2.00
Fossil fuels(%)	55%	44%	24%	12%	43%	18%	9%
Non-fossil fuels(%)	45%	56%	76%	88%	57%	82%	91%
Renewable(%)	42%	53%	74%	86%	55%	80%	90%

14th Five-Year Plan period: a critical period to make a big step forward in the energy transition

From 2018 to 2025, renewable energy continues to accelerate the capacity expansion and supplies the incremental electricity demand. In the Below 2 °C Scenario from 2020 to 2025, the share of renewable capacity increases 13 percentage points in this period, and the share of renewable generation increases 9 percentage points, which mainly attributes to wind and solar PV. Both capacity and generation of solar and wind reach to more than twice, given an average annual newly installation of 53GW of wind and 58GW of solar PV respectively. In 2025, power generation of solar PV and wind reaches more than 21% of the total power generation.

Biomass capacity increases 43% and generation increases 57%. Biomass generation contributes to 2.2% of total generation in 2025. Hydro and geothermal power also slightly increase in this period, and ocean power technology, still in R&D phase, grows to only 550 MW by 2025.

As for coal, to facilitate the structural reform and proceed energy transition, its capacity does not see significant increase during the 14th Five-Year Plan period. The overall capacity of coal maintains within 1100 GW. Although coal capacity keeps stable, coal-based generation increases a little in the two scenarios, as renewable energy is not completely cost competitive with coal. In addition, the infrastructure is still undertaking the transition that limits the scale of renewable integration. The replacement of small and inefficient coal plants by clean and efficient coal technology and the retrofit of coal plants to increase operational efficiency and flexibility are two major features for coal power industry. Natural gas and nuclear also slightly increase from 2020 to 2025, while the generation share of natural gas and nuclear keeps relatively stable in both scenarios.

The power supply structure is with a good pace of energy transition. As the capacity of renewable energy keeps growing while it of coal maintains stable, the share of renewable power capacity and generation keeps increasing. In 2020, the share of coal capacity decreases to just a half, while coal-based generation still supplies 60%~62% of total power demand, and renewable generation contributes 28%~29%. In 2025, these figures have been reshaped to 34%~38% of generation supplied by renewable energy, while coal only supplies about half of the total demand.

As a typical lifetime of coal fired plant is around 30-40 years, and the majority of existing fleet of coal plants are built after 2005, 14th Five-Year Plan period is very critical to maintain the size of coal fleet and continue to adjust the power supply mix. In this case, the peak CO_2 emission can come in 2030 at a rather lower level and the trajectory of CO_2 emission can be bended easily and less costly in the 2030's.

2025 to 2050: Consolidation of the position of renewable energy, and achieving successful energy transition in power sector

After 2025, renewable energy replaces existing fossil fuels and grow faster, and coal continuously decline. From 2025 to 2035, wind and solar increase fast, where both wind and solar capacities in 2035 are about tripled compared to 2025 in the two scenarios. Average annual new installations is around 126 GW of wind and 129 GW of solar PV in the Below 2°C Scenario, 70 GW of wind and 85 GW of solar PV in the Stated Policies Scenario. Such speed continues to around 2040 and start to decrease. Due to low growth rate of electricity consumption, a rather large share of renewable in the power mix and the decommissioning of capacities built around 2015, total wind and solar capacity increases less than a half in 2025-2035 period. Biomass keeps relatively unchanged power capacity and generation after 2025 due to the limitation of biomass resource, and hydro, geothermal, ocean and nuclear capacity experience a continuously increase in the two scenarios.

Coal capacity gradually declines from 2025 to 2050, while its generation sees a more significant drop during the period of 2030-2035. The role of coal plants is turned to providing flexibility and spinning reserve from simply serving the base load. In the Below 2 °C Scenario, the average full load operating hours drops from 4394 hours in 2025 to less than 2500 hours in 2035. In Stated policies, coal plants enjoy a smoother drop of generation due to the lack of CO_2 emission constraint and the CO_2 price is rather low in this period. After 2035, the contribution from coal in the generation mix becomes less significant and the share of coal generation drops under 26%.

Natural gas capacity shows quite different trend in the two scenarios. In Stated Policy Scenario, natural gas capacity increases at first to speed up the coal replacement, and after 2040, it declines due to the lack of cost competitiveness. While in the Below 2 °C Scenario, to substitute more coal in an earlier stage/further decarbonize the system, in order to increase more flexibility to adapt to higher proportion of renewable energy, natural gas capacity grows continuously.

Considering the trends of different sources, the share of renewable capacity before 2035 increases far faster than it after 2035, and the share of coal capacity also has a faster decline rate before 2035. The similar trends happen in power generation. In the Below 2 °C Scenario, share of coal generation is 14% in 2035 and 5% in 2050, share of renewable generation is 73% by 2035 and 87% in 2050. Notably, the share of wind generation is the largest among all types of sources after 2030 in the Below 2 °C Scenario, and after 2035 in the Stated Policy Scenario, indicating a significant potential of wind generation.

Figure 9-3: Installed capacity by technology through to 2050 in the Stated Policies Scenario (top) and Below 2 °C Scenario (down)

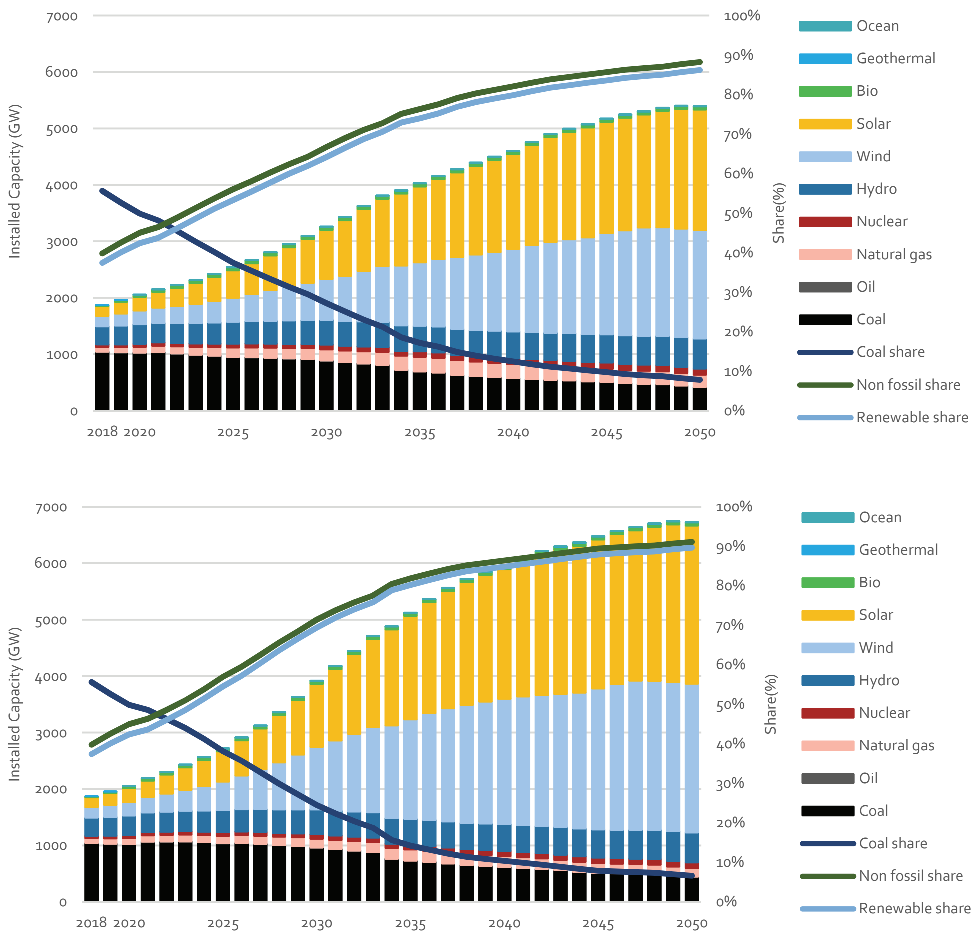
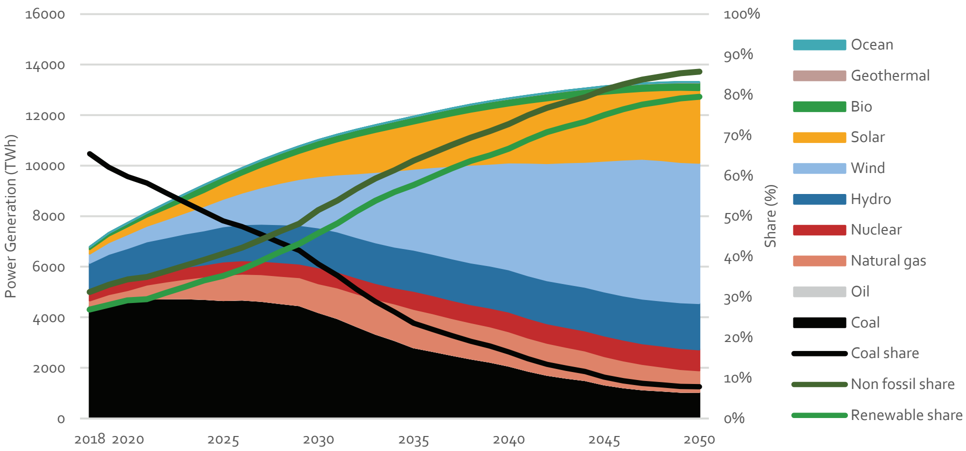
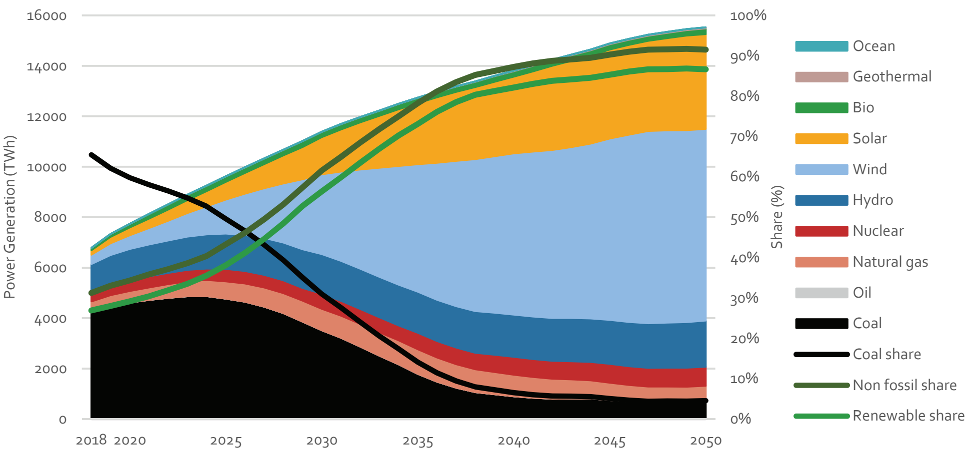


Figure 9-4: Generation by technology through to 2050 in the Stated Policies Scenario (top) and Below 2 °C Scenario (down)





9.4 Power system economics, generation technologies cost reduction

Generation cost development

Figure 9-5 displays the assumed development in levelised cost of electricity (LCOE) for typical electricity generation technologies for the years 2020-2050. It can be seen that CCGT natural gas and CHP coal will have constant LCOE values of 451 and 326 RMB/MWh, respectively. However, as the anticipated cost of solar and wind falls, the figure shows how RE technologies can achieve cost parity during the 2020-2030 period. Specifically, for offshore wind power, the LCOE value is of 423 RMB/MWh in 2020, 330 RMB/MWh in 2030 and 225 RMB/MWh in 2050. Regarding onshore wind power, the LCOE value is of 267 RMB/MWh in 2020, 223 RMB/MWh in 2030 and 193 RMB/MWh in 2050. Solar PV has a LCOE of 353 RMB/MWh in 2020, 300 RMB/MWh in 2030 and 227 RMB/MWh in 2050. Solar PV rooftop has a LCOE of 316 RMB/MWh in 2020, 270 RMB/MWh in 2030 and 237 RMB/MWh in 2050. Although the trends consider the national case of China, it is true that

LCOE values depend also on local conditions of technology installation (which can affect the full load hours). Therefore, different provinces might have different LCOE for the same technology. Figure 9-5 shows the range for wind power. In 2020, the LCOE for wind power varies between 266 and 498 RMB/MWh; in 2030, between 222 and 390 RMB/MWh; in 2050, between 193 and 268 RMB/MWh. It emerges that the cost difference between provinces decreases over years, going from 232 RMB/MWh to 75 RMB/MWh, i.e. limiting the provincial cost variability. Besides the variability of the LCOE, it emerges overall that from 2040 RES technologies will always be more cost-effective than coal and natural gas.

Figure 9-5: Comparison of levelised costs of electricity (LCOE) by technology from 2015 to 2050

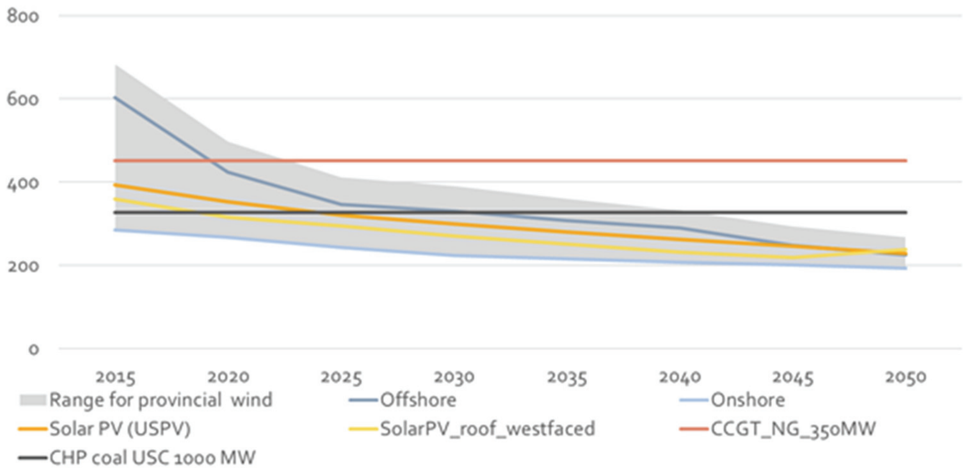
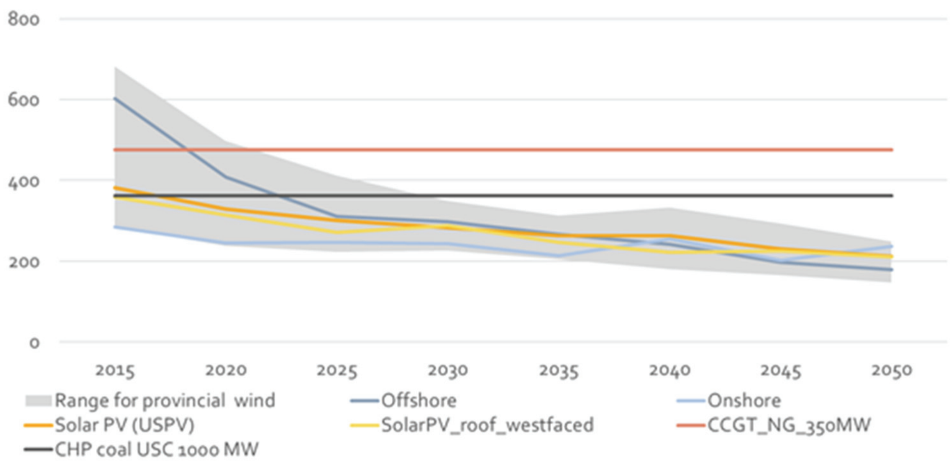


Figure 9-6: Comparison of value adjusted levelised costs of electricity (VALCOE) by technology from 2015 to 2050



By including the system' costs into the LCOE analysis, we can also analyse the value-adjusted levelised costs of electricity (VALCOE). The trends for different technologies are presented in Figure 9-6 for the years 2020-2050. Overall, it emerges that RES become even more cost-efficient than coal and natural gas, reaching cost parity by 2025. Specifically, natural gas and coal have constant VALCOE to 475 RMB/MWh and 361 RMB/MWh. Offshore wind power has a VALCOE value of 408 RMB/MWh in 2020, 297 RMB/MWh in 2030 and 178 RMB/MWh in 2050. Onshore wind power has a VALCOE value of 244 RMB/MWh in 2020, 243 RMB/MWh in 2030 and 237 RMB/MWh in 2050. PV solar has a VALCOE value of 329 RMB/MWh in 2020, 282 RMB/MWh in 2030 and 212 RMB/MWh in 2050. PV solar rooftop has a VALCOE value of 314 RMB/MWh in 2020, 287 RMB/MWh in 2030 and 210 RMB/MWh in 2050. When analysing the provincial range of VALCOE values, it can be seen that the range varies from 237 to 498 RMB/MWh in 2020; from 226 to 349 RMB/MWh in 2030 and from 147 to 248 RMB/MWh. Overall the cost variability decreases overall among the years, from 261 RMB/MWh in 2020 to 123 and 101 RMB/MWh in 2030 and 2050, respectively. Furthermore, consistently to the previous results of LCOE, it emerges from the VALCOE analysis that RES are always more cost-efficient than coal and natural gas from 2030.

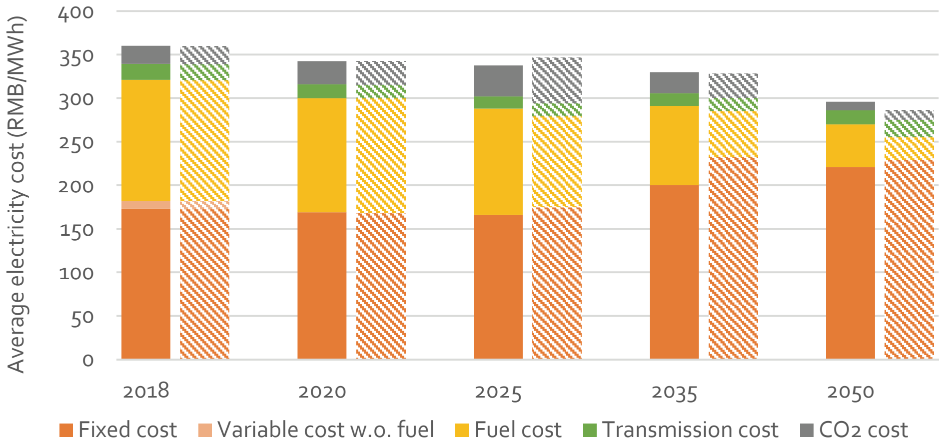
Table 9-3: Cost reduction trends of typical emerging technologies

Year	RMB/kW	Wind			PV		Chemical storage
		Onshore	DG	Offshore	Utility scale	DG	
2020	Investment	6900	8250	15000	3600	3420	Investment cost is 1.5 RMB/Wh, and the cycle lifetime is 4000 rounds.
	O&M	145	154	290	68.4	85.5	
2025	Investment	6500	7700	12800	3300	3135	Investment cost is 1.2 RMB/Wh, and the cost of "DG+storage" is competitive for commercial users.
	O&M	142	150	285	67.2	84.5	
2035	Investment	6200	7250	8900	2870	2640	Investment cost is 1 RMB/Wh. The cycle lifetime is more than 10000 rounds.
	O&M	139	144	277	65.5	87.8	
2050	Investment	5950	6830	7800	2460	2265	Investment cost is 0.5 RMB/Wh. Applications on providing flexibility to grid is cost competitive.
	O&M	135	140	270	63.7	88.3	

Overall electricity cost composition and development

Average electricity cost in the Below 2 °C Scenario shows a more significant downward trend in the future than that in the Stated Policies Scenario from 2018 to 2050. Under the Below 2 °C Scenario, the average electricity cost in 2050 drops to 353 RMB per MWh, 64.4% of the 2018 level. From the perspective of cost composition, fixed cost gradually becomes the main source of cost, both proportion and absolute value increase year by year, while the proportion and absolute value of variable cost and fuel cost decrease significantly due to the increase of the share of renewable energy. CO_2 cost plays an important role during the transition, as can be seen in Figure 9-7, CO_2 cost in 2025 is much higher than the rest years to strengthen the cost competitiveness of low-carbon technologies, and is decreased once the low-carbon generation becomes the major part of the power mix.

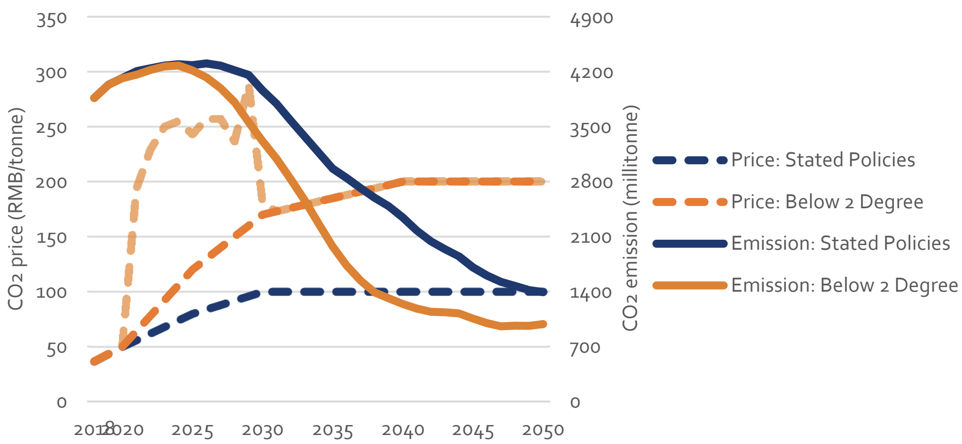
Figure 9-7: 2018-2050 average electricity cost and its composition in the Stated Policies Scenario (left column) and Below 2 °C Scenario (right column).



CO_2 cost curves are derived from predefined CO_2 prices in both scenarios and total CO_2 budget in the Below 2 °C Scenario. CO_2 emission cost has been projected with an upward trend since 2018 and finally stabilize at 100 RMB/tonne in the Stated Policies Scenario and 200 RMB/tonne in the Below 2 °C Scenario. Due to a more ambitious emission reduction pathway, marginal cost of power sector emission in the Below 2 °C Scenario shows that current CO_2 price level is not sufficient to reduce CO_2 emissions during the period of 2020 to 2030 to achieve a sufficient reduction of CO_2 intensity.

Total carbon emissions in the Below 2 °C Scenario is predicted to decline significantly in the decade after 2027 driven by CO_2 budget allocated to power sector and cost reduction and efficiency improvements of renewable power. Carbon emissions in the Stated Policies Scenario decrease more gradually year by year, with a projected total emission of 1.5 billion tonnes in 2050, which is higher than the total emission of 1.14 billion tonnes in 2050 in the Below 2 °C Scenario.

Figure 9-8: 2018-2050 marginal cost of power sector emissions



Note: lighter coloured dash line represents the shadow price by CO_2 maximal emission suggested in the Below 2 °C Scenario.

9.5 Development of wind power

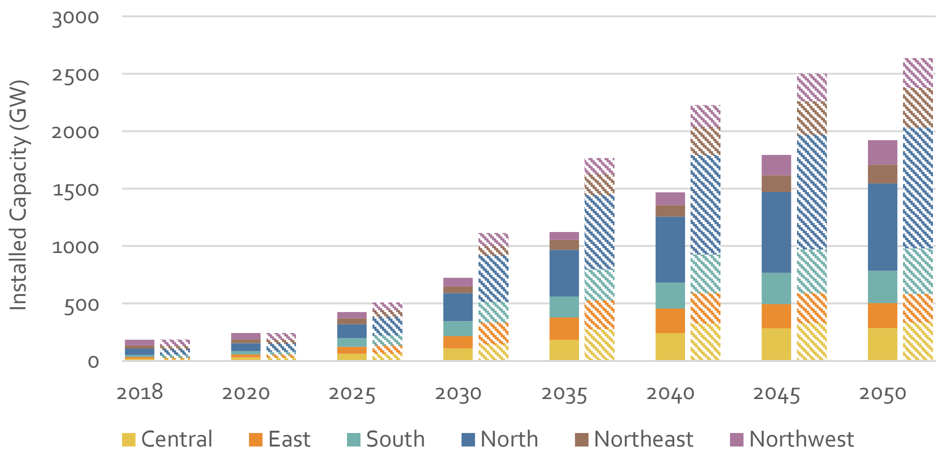
As one of the mature renewable power technologies, wind power is a leading renewable source in the energy transition in China. Onshore wind power in low-wind-speed areas and offshore wind power become gradually important after a rapid growth of centralised onshore wind power projects in Northwest and Northeast China. Electricity demand distribution and land resource availability become two important factors for wind resource utilisation. The development of wind power shows significant shifts in different periods on distribution and technology choices.

Supported by China's renewable energy policies, and driven by cost reduction, wind power industry maintains a steady growth during the 13th Five-Year Plan period, which leads to a cumulative capacity of 242 GW in 2020, of which offshore wind is more than 6 GW. This number fulfils the minimal capacity target set in China's Renewable Energy 13th Five-Year Plan, 210 GW in 2020, of which offshore wind should be at least 5GW.

In the period of China's 14th Five-Year Plan from 2020 to 2025, wind capacity experiences a rapid growth, increasing about 76% to 425 GW in 2025 in the Stated Policies Scenario and about 110% to 507 GW in the Below 2 °C Scenario. New installed capacity in 14th Five-Year Plan is expected to be 37~53 GW per year on average. China's wind power development has gradually shifted from the "Three Norths" provinces to the South, East and Central China to match the electricity demand and to optimize the power flow. By 2025, the capacity in these regions is approx. three times as much as 2020 in the Below 2 °C Scenario, while Northeast and Northwest have a relatively slow growth.

In the mid and long term, wind power capacity will be further expanded. In the Below 2°C Scenario, it is about more than seven times in 2035 of the capacity in 2020, and almost eleven times in 2050. Compared to Below 2°C Scenario, Stated Policy Scenario has a relatively slower increase in the long term, and the capacity is more than four times in 2035 and eight times in 2050. It is notable that the capacity growth will be slower after 2035, due to the limitation of cost-effective wind potential and saturation in electricity demand. The share of wind power capacity in "Three Norths" decreases in mid-term, while in the long term, the capacity share increases once again, to further expand the capacity with better connected grid conditions.

Figure 9-9: China installed wind capacity by region in the Stated Policies Scenario (left column) and Below 2 °C Scenario (right column)



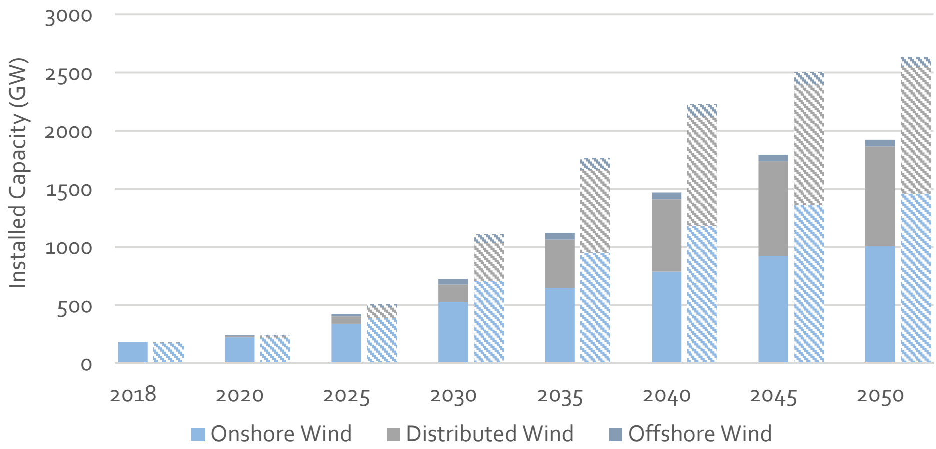
The model has assumed a rather ambitious developing conditions for distributed wind, for the good of better utilising the land with multiple usage and matching the generation with local demand. Industrial parks and edges of farmlands are mostly considered for developing distributed wind. Statistics on farmlands[227], lists of industrial parks[228] and the geographical conditions [229] of different provinces are used to calibrate the resource potential in the scenarios. The overall distributed wind potential is approx. 800 MW, of which the potential in South, East and Centre China covers 51%.

Given similar wind power resources or efficiency, distributed wind has advantages on saving the transmission capacity and losses. In the Below 2 °C Scenario, onshore wind capacity increases from 236 GW in 2020 to 1666 GW in 2035, of which the share of distributed wind capacity increases from 5.5% in 2020 to 43% in 2035, reaching to 715 GW. After 2035, along with the saturation of resource potential, the share stops significant increase. More economically feasible utility scale projects are developed in "Three Norths" provinces.

Offshore wind technology has become mature in recent years. The results also indicate the further development of offshore wind. As most of the coastal provinces are mostly populated and developed, the electricity demand is rich. Offshore wind shows the benefits on reducing system cost through avoiding long-distance electricity transmission. However, due to the limited potential in near shore and less attractive resources in near shore, the share of offshore wind maintains insignificant.

The capacity of offshore wind reaches 23 GW in 2025, 97 GW in 2035 and 86 GW in 2050 in the Below 2°C Scenario, while it is 22 GW in 2025, 58.2 GW in 2035 and 57.7 GW in 2050 in the Stated Policies Scenario. It increases about 3 GW per year during the 14th Five-Year Plan period in both scenarios. After 2025, it sees more significant growth between 2025 and 2035 in the Below 2°C Scenario, and the average annual new installation is approx. 7.4 GW.

Figure 9-10: China installed wind capacity by technology in the Stated Policies Scenario (left column) and Below 2 °C Scenario (right column)



9.6 Development of solar power

Solar PV has experienced a rapid growth since 2012, driven by the advances of technology and rapid cost reduction. It has become one of the most competitive technology that accelerates the energy transition worldwide and in China. Solar PV, especially distributed PV for self-use, is becoming cost competitive in a very short period. CSP has the potential on providing flexibility and inertia to the system. However, due to limited potential sites and high cost compared with solar PV, CSP will not have a large share in the capacity mix.

The capacity of solar power in 2018 around the whole country is 175 GW, with development of two years, till 2020, the total capacity will reach 246 GW in both scenarios, indicating a rapid development of solar power. By 2020, even though distributed PV keeps a high growth rate, utility-scale PV is still the majority and shares 67% of the total solar capacity.

In the period of China's 14th Five-Year Plan from 2020 to 2025, solar capacity still experiences rapid growth, about 58 GW increase per year on average, and reaches 536 GW by 2025 in the Below 2°C Scenario, more than twice compared to 2020. In "Three Norths", especially in northwest of China, solar PV is less attractive to be transferred through long transmission lines, therefore, more solar power will be developed in other regions. The share of capacity in "Three Norths" continuously declines, from 54% in 2020 to 52% in 2025, and the share in Northwest decreases faster, from 26% in 2020 to only 17% in 2025 in the Below 2 °C Scenario. Utility-scale solar PV still has the largest share and has doubled in

14th Five-Year Plan period, while distributed solar PV is about twice by 2025, CSP is about five times in 2025. The share of CSP is still quite small, only 0.7% of the total in 2025 in the Below 2 °C Scenario. The average annual growth is approx. 58 GW of solar PV, and the overall capacity reaches 532 GW in 2025 in the Below 2 °C Scenario. Due to less electricity demand and cheaper CO2 cost in the Stated Policies Scenario, the growth of solar is less during 14th Five-Year Plan period. The average annual growth is approx. 47 GW of solar PV, and the overall capacity reaches 481 GW in 2025 in the Stated Policies Scenario.

In the long term, solar power keeps a fast expansion. The total solar capacity achieves about 1836 GW in 2035 and 2803 GW in 2050 in the Below 2 °C Scenario. The Stated Policy Scenario has a relatively slow growth rate and the solar capacity will achieve approx. 1346 GW in 2035 and 2135 GW in 2050. The growth rate of total solar capacity in both scenarios becomes slower after 2035. In the Below 2 °C Scenario, utility-scale PV has the largest share and accounts for 66% both in 2035 and in 2050. Distributed solar PV also increases a lot, and accounts for 33% in 2035 and in 2050. However, due to the limitation of technology and economic factors of CSP, CSP only accounts for 0.57% in 2050. New installed solar capacity also shows the regional transfer from "Three Norths" to other regions for better distribution until 2035, and after 2035, the new capacities are built more in "Three Norths".

Figure 9-11: China installed solar PV capacity by region in the Stated Policies Scenario (left column) and Below 2 °C Scenario (right column)

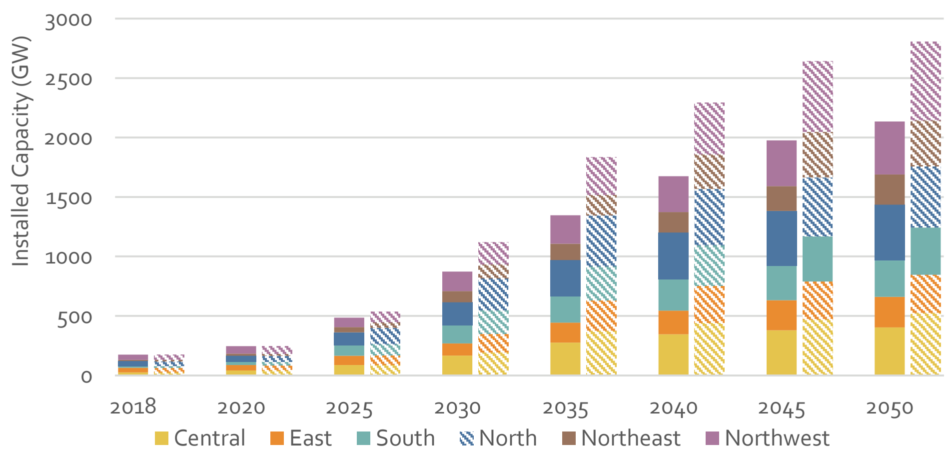
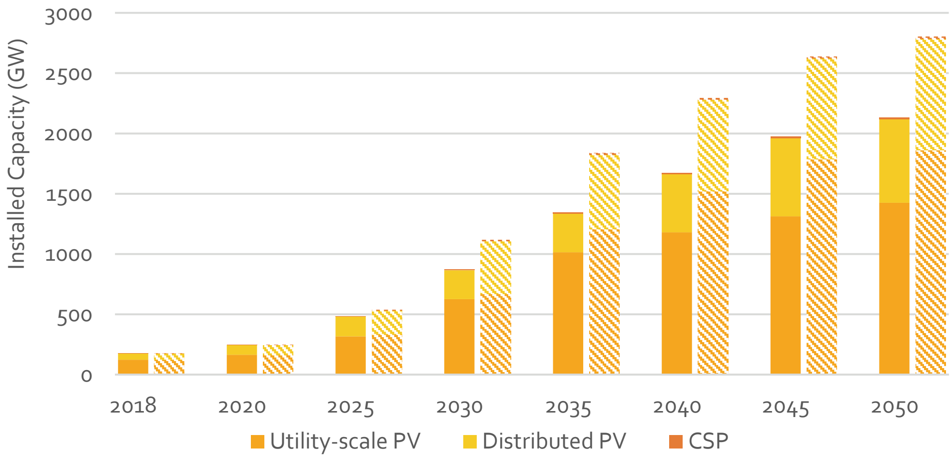


Figure 9-12: China installed solar PV capacity by technology in the Stated Policies Scenario (left column) and Below 2 °C Scenario (right column)



9.7 Power market development

Currently, China is under the power system reform, in which long term markets are established, market operators are built, and spot market pilots are being constructed (see Part 1 for more detailed description). The power market reform is a very important element to support the energy transition. It will strongly affect the principles of power system operation and thus the LCOEs and relative value of competing technologies. Through the built-out of market rules, it allows sufficient competition between market players that can lead to minimal overall cost and value-based investment decisions. In addition, by integrating provincial and regional markets, power system balancing, and efficient utilization of flexible resources can be achieved in a larger scale.

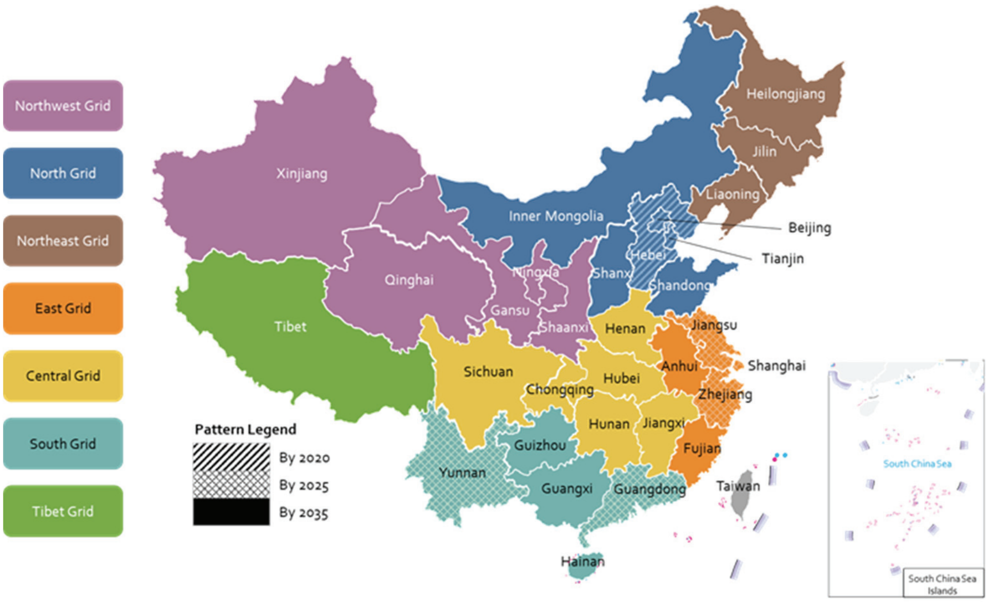
Four sets of initial non-market properties represent corresponding aspects of the current power sector framework. In the scenarios, these are gradually reduced to reflect power sector reform progress.

- Generation rights, such as rights awarded to generators based on a perceived fair principle of allocation between market participants and generation assets. Designed full-load operating hours according to technology types will be gradually removed and replaced by economic dispatch, which schedule the power generation based on economic merit order.
- Interprovincial transmission scheduling, in which flow schedules are adopted initially by setting constant levels of flow for day-time and night-time. Such fixed schedule will be further released by mobilising the flexibility among regions to achieve a larger-scale balancing.

Economic dispatch is achieved by establishing whole sale spot markets. The value of short-term flexibility on balancing the system is reflected in such scheme. Regional spot markets are introduced based on the current progress of pilot provinces as well as our projection towards future.

- Jing-Jin-Ji regional market is the first one established before 2020, as suggested by NEA in 2016 with the release of Notice to Prepare for the Establishment of Jing-Jin-Ji Electricity Market, and a Jing-Jin-Ji Integrated Renewable Energy Consumption Plan is already underway in early 2018.
- As an extension of Guangdong's spot market and as a strong provider of hydro power, Yunnan will join Guangdong's market during 14th Five-Year Plan period. Through well connected grid, Shanghai, Jiangsu and Zhejiang will also be connected in a rather early stage.
- During the period of 2025 to 2035, large regional markets will be established according to the grid structure. As Jing-Jin-Ji area highly depends on the electricity provided from West Inner Mongolia, the Jing-Jin-Ji market will be expanded earlier than those large regional markets in the first few years of 15th Five-Year Plan period. By 2035, northeast, north, northwest, east, centre and south regional markets will be all established before 2035.
- After 2035, it is assumed regional markets continue to be connected and a national market is set up around 2040, so that power is balanced within the whole country through an efficient national market, and flexible sources can be more efficiently dispatched.

Figure 9-13: Timeline of regional spot power market establishment



In addition to dispatching existing sources, more assumption is made on new flexible sources. The projections of both scenarios also assume market signals enable participation of end-users in balancing power markets, including:

- Demand-side flexibility, such as reducing air conditioning loads or shifting industrial processes.
- Smart charging of electric vehicles to times with low system marginal costs and correspondingly low market prices, and correspondingly avoiding times with high market prices.

To ensure an efficient and cost-effective dispatch of resource, electricity market should make sure to cover as many players as possible to encourage sufficient competition and limit the capability of large players on price lobbying. In addition to spot market, it is also important to establish long-term market to facilitate the risks of price variations and ancillary market to initiate flexible sources on providing grid services. Efficient retail markets with time-dynamic prices is an efficient way to ensure that the consumers receive the right prices signals and react on flexibility needs.

9.8 Power grid development

Interprovincial grid expansion is critical to provide stability and balancing support, especially when the grid needs to integrate high penetration of variable renewable sources. In the model, transmission grid expansion is planned according to least-cost principles in order to efficiently transfer electricity and ensure system security. In the short term, it is assumed that all lines currently planned or under construction will be completed. After 2020, new lines are added to support electricity demand growth and integrate more renewables in the power system.

From 2020 to 2050, total interprovincial grid capacity within different regions is expanded 682 GW amounting to 89% increase in the Stated Policies Scenario and 781 GW amounting to 116% increase in the Below 2 °C Scenario, from 361 GW in 2020. Interregional grid capacity and power transmission has similar trends as within the regions and the growth is even sharper. In the Below 2 °C Scenario, the grid capacity is expanded from 411 GW in 2020 to 506 GW in 2025, amounting to 23% increase. The corresponding growth is smoother in the Stated Policies Scenario, amounting to 16% increase. The capacity expansion becomes faster afterwards. The size of overall capacity in 2050 is more than doubled in the Below 2 °C Scenario and in the Stated Policies Scenario, compared to the number in 2020.

Figure 9-14: Interprovincial grid capacity within the same regional grid in the Stated Policies Scenario (left column) and Below 2 °C Scenario (right column)

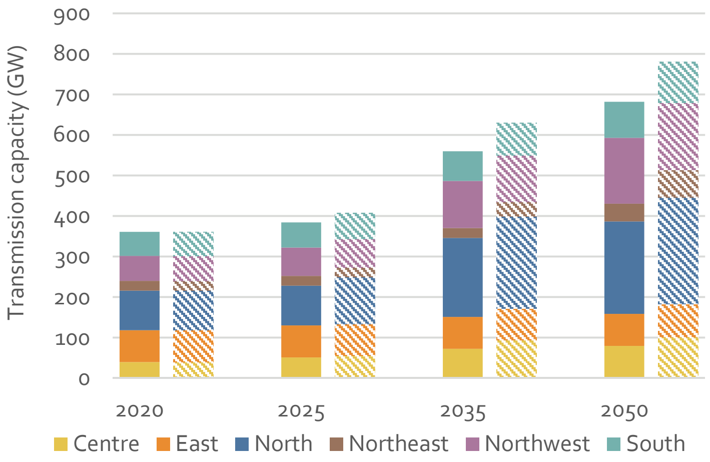
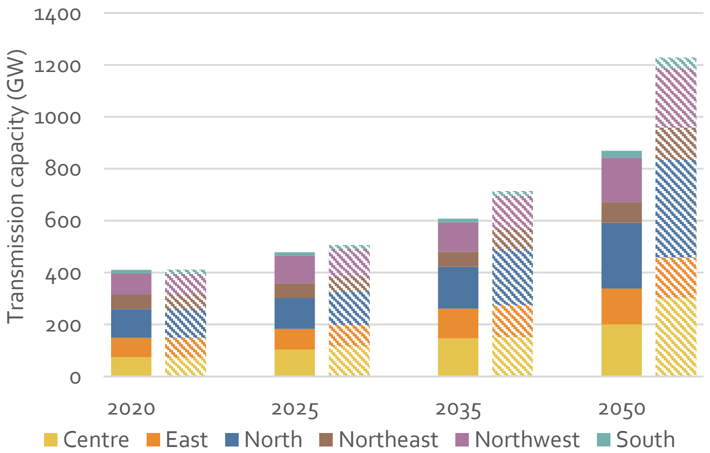


Figure 9-15: Interprovincial grid capacity connecting different regional grids in the Stated Policies Scenario (left column) and Below 2 °C Scenario (right column)



Interregional transmission's substantial growth indicates the need to improve interconnection among regional grids. China's current load centres are in the north, central, and east, whereas renewable energy bases are mainly in the northwest, northeast, north and centre, with hydropower mainly in Sichuan and Yunnan. In the long term, less developed but populated regions, such as in Central China, will experience higher shares of electricity demand growth. Increased transmission allows better integration of renewable energy into the grid and balancing over a larger area, enabling greater energy efficiency system-wide. Therefore, increased transmission capacity is needed to support regional demand growth as well as integration of renewables. Grid development was previously driven by electricity demand growth, but in the future increasing penetration of renewables will require more frequent and larger sized balancing resources. It is also reflected by the following figures. One thing to be noted is that bidirectional power exchange becomes more frequent on daily and seasonal basis to achieve power balance through shared flexibility, in addition to long distance single direction power flow. Such figures suggest that power grid should be dynamically operated so that flexible source can be shared in a larger expand.

Figure 9-16: Power transmission between regions in 2020

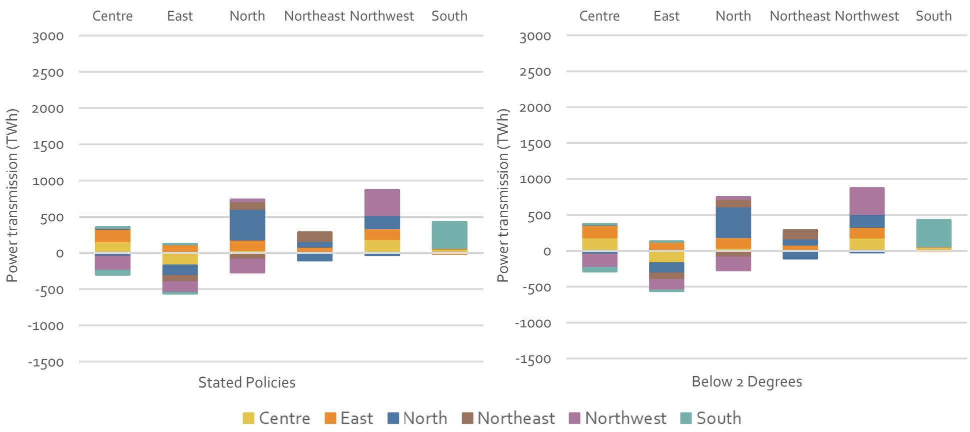


Figure 9-17: Power transmission between regions in 2025

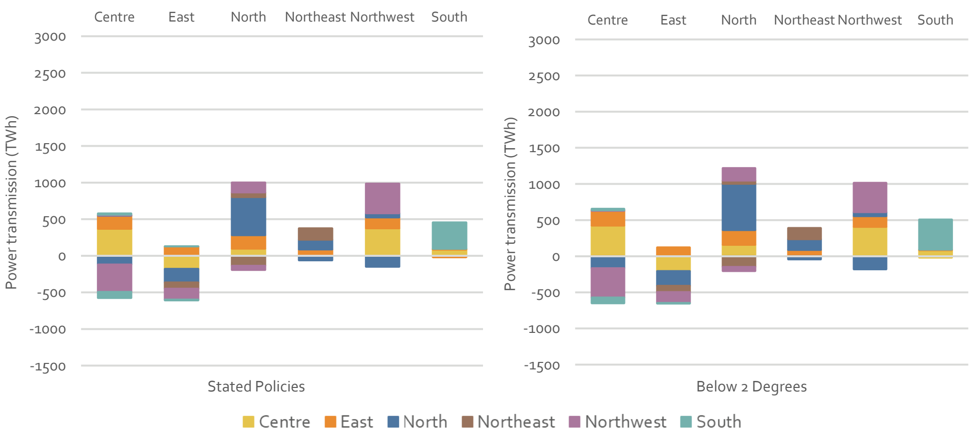


Figure 9-18: Power transmission between regions in 2035

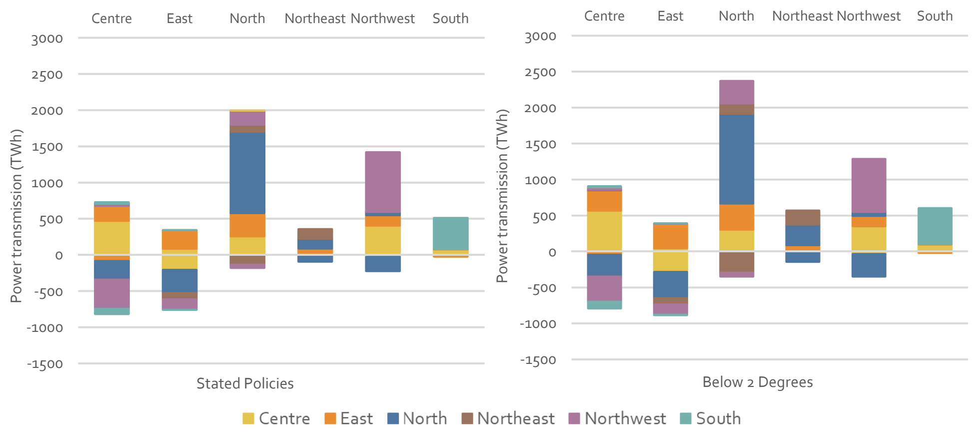
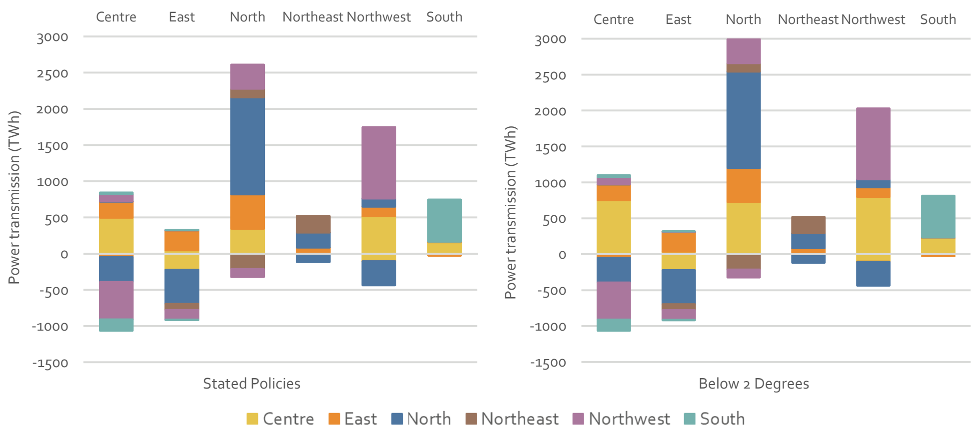


Figure 9-19: Power transmission between regions in 2050



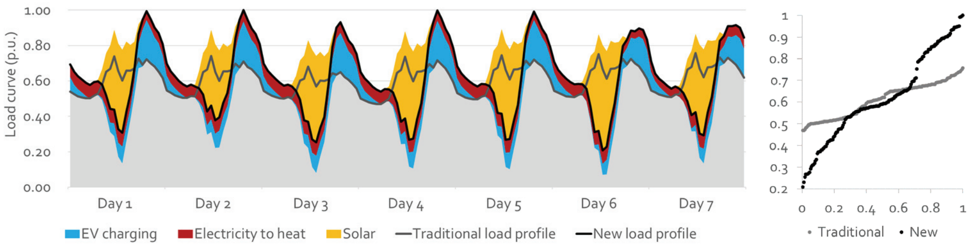
A power grid that has a good network structure and dynamic grid operation is an important form of flexibility, which is sometimes overlooked. It is very important that grid planning process includes the perspectives from market development so that the system operation can maximise the overall societal good. The cost-benefit analysis should consider the integration of renewable energy as well as other forms of generation or consumption, but not just the generation growth of electricity demand.

In addition, the focus on distribution grid development should be shifted from connecting the country and achieving universal access, towards development of intelligent distribution grids to connect distributed generation, EVs etc.

9.9 Flexibility in the system

The shape of inflexible part of the net load is significantly changed by distributed energy resource (DER), including EVs, heat pumps as well as distributed generation (DG), such as roof-top PVs. The ratios between peaks and valleys are getting larger with higher penetration of DERs. Fast ramping flexibility is needed to keep the balance of production and consumption. Flexibility need to be exploited from both generation and consumption side, and system balancing paradigms need to be shifted with a more integrated view.

Figure 9-20: Load curves (left column) with integration of DER in 2050 winter and its CDF plot (right column).



More complex grid operation and shifted balancing paradigm

With a large penetration of variable renewables, system operating paradigms shift towards covering the variability of renewable production by providing more flexibility in the operation, handling uncertainties with better forecasting and more reserve capacity, and balancing the system both locally with distributed power sources and storage, as well as by improving inter-regional power exchange.

Following figures show the transition on system balancing. On the production side, it is observed that the share of coal generation is significantly reduced while the share of renewable power is increased during the transition. The introduction of flexible sources in both production and consumption side reshapes the load curve. Flexible resources are mobilized to accommodate the variations of wind and solar production, as well as sharp charging load from EVs, especially during the afternoon hours. After peaking at noon, solar production reduces rapidly while the power consumption picks up very quickly until the evening peak time, during which storages together with smart charging of EVs and demand response play significant roles in balancing the system.

Figure 9-21: Power generation and consumption profile in China in 2020

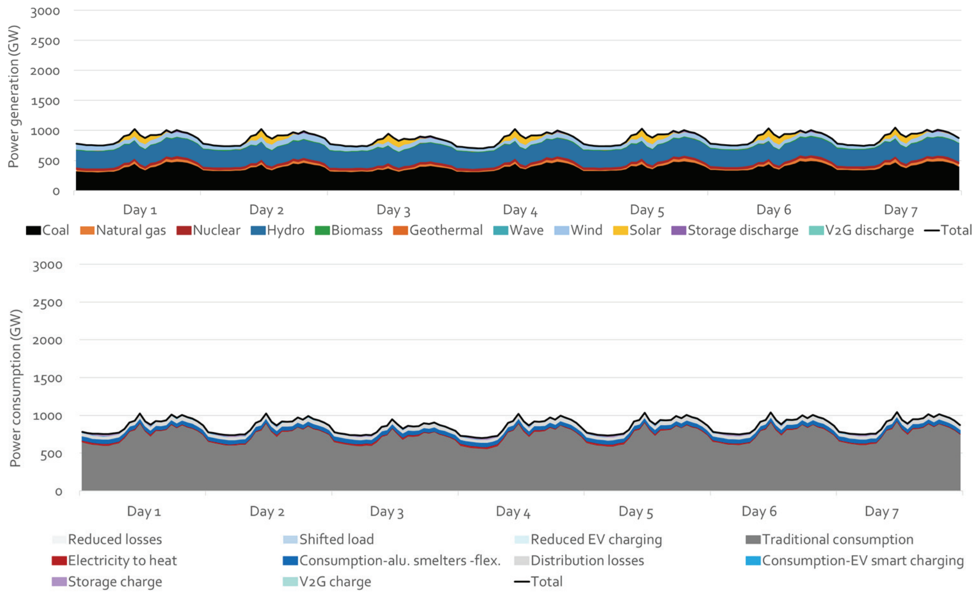


Figure 9-22: Power generation and consumption profile in China in 2035 Winter (Below 2 °C Scenario)

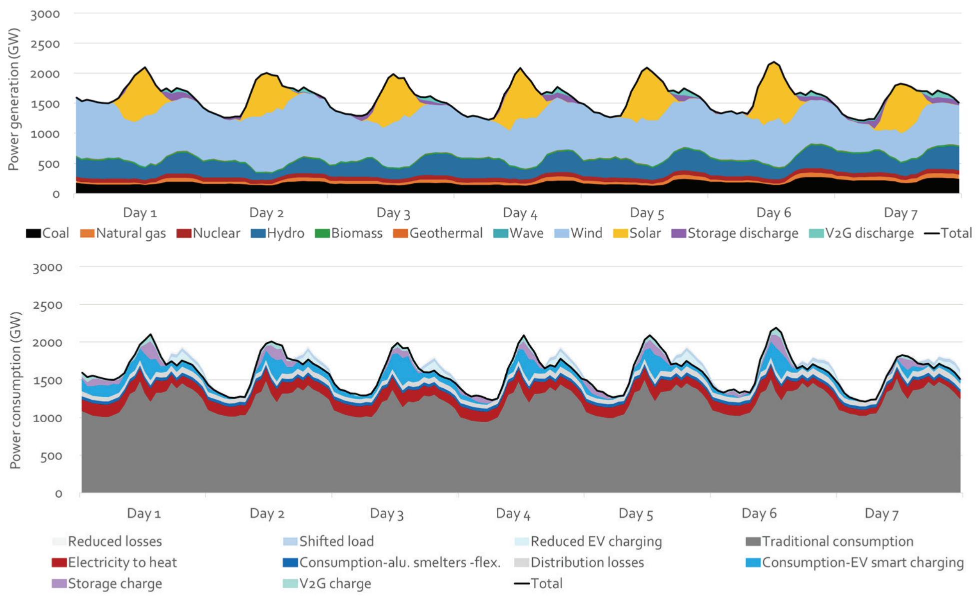
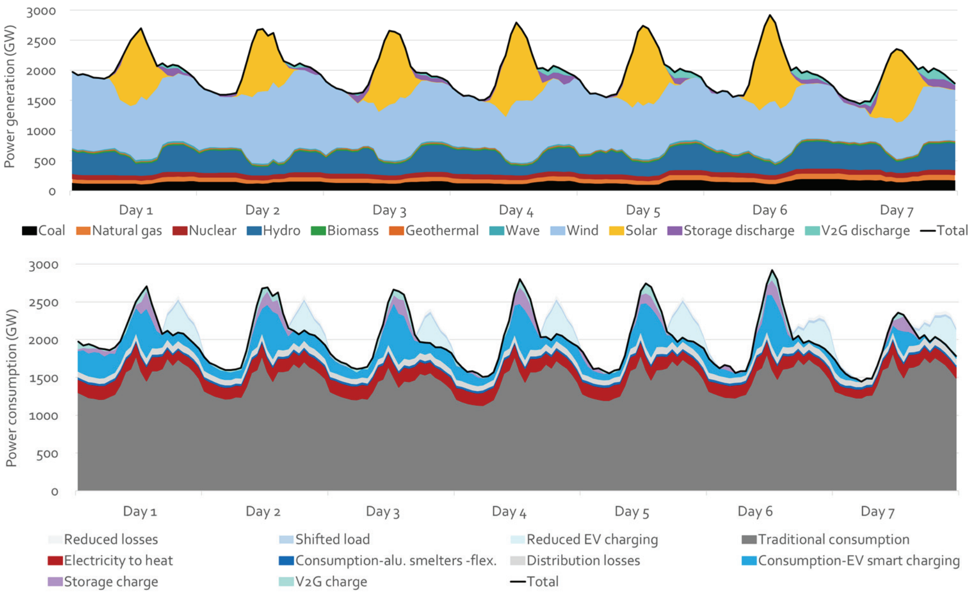


Figure 9-23: Power generation and consumption profile in China in 2050 Winter (Below 2 °C Scenario)



The incremental part of electricity consumption is composed by the increase from conventional electrical usage and new appliances, such as EVs and heat pumps. The electricity consumption profile becomes more fluctuant and more inflexible sources are placed in the system. In Below °C Scenario, the net load peak value in 2020 winter is 1045 GW while the valley value is 700 GW, which lead to the difference as 345 GW. In 2035 winter, the peak value becomes 2190 GW and the valley value becomes 1213 GW. The difference increases a lot to 977 GW. In 2050 winter, the peak value is 2921 GW and the valley value is 1447 GW. The difference further increases to 1474 GW. The shape of net load profile does not depend on electricity consumption but depends on the inflexible part on both consumption and generation sides. The shapes of wind and solar production profiles decide when a peak appears in the system.

In both power generation side and consumption side, various flexible sources, including storage, V2G, load shifting, and EV charging are mobilized to accommodate the power system fluctuation caused by high share of VREs. The share of mobilized power consumption becomes larger. It is illustrated in the figures that by 2050, the maximal capacity of flexibility provided on the consumption side is almost equivalent to the flexibility provided from generation side by hydro and thermal plants in the Below 2°C Scenario. Considering the additional needs of upgrading chargers and battery management systems of EVs when activating V2G service as well as the risks of battery degradation through such services, the cost of V2G is much higher than smart charging. Therefore, the volume of flexibility of V2G is much less than smart charging services.

Chapter 7 provides an overview of transport sector and discussions on the benefits and limitations of the flexibility provided by EVs.

Interprovincial transmission operation supports system balancing via bidirectional exchange

Following figures illustrate power exchange in 2020 and 2035 between Shanxi Province and other provinces. In 2020, Shanxi mostly exports power to neighbouring load centres, such as the Jing-Jin-Ji area, Shandong and Henan, and imports power from West Inner Mongolia and Shaanxi. Fixed set points are applied in these transmission lines. While the operation schedule is relaxed, and a spot market is introduced to assist on system balancing, the operation of inter-provincial transmission becomes more flexible. By 2035 power exchanges become volatile and bidirectional power flows appear. Such transition indicates that more flexible power exchange provides strong support to accommodate high penetration levels of renewables. By 2050, a national market is established, and more flexible power operation is implemented. Power system balancing can be achieved in broader region, the balancing capacity is much larger and bidirectional power flow appears more and more. In 2050, Shanxi exports most to Henan, and imports most from west Inner Mongolia.

Figure 9-24: Power exchange between Shanxi and its connected provinces in 2020 winter

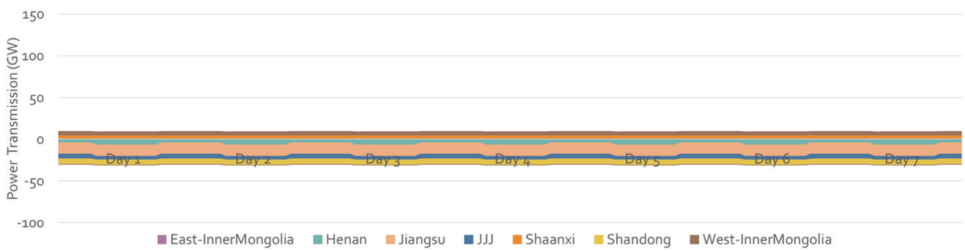
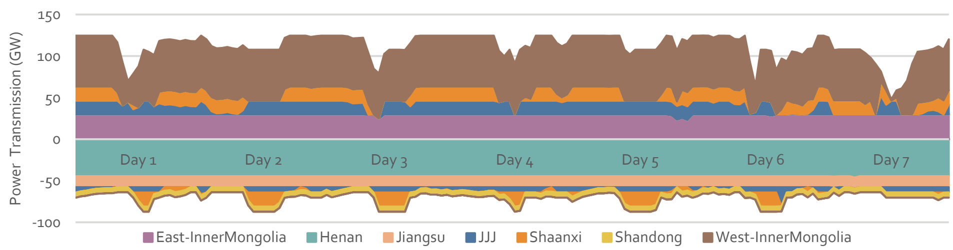


Figure 9-25: Power exchange between Shanxi and its connected provinces in 2050 winter



Demand response of industrial load provides a large potential of flexibility

The increasing share of renewable energy sources in the national generation portfolios is introducing a significant amount of uncertainty and fluctuations in power system dynamics, which must be properly handled in order to guarantee system balancing.

Demand-side management is a promising solution to address the need of flexibility in power systems. It relies on changing the way consumers use electricity and can be implemented in two ways, i.e., by increasing loads' energy efficiency or through demand response. Demand response promotes changes in electricity demand by relying on the flexibility of consumers, which are compensated through economic incentives. In other words, in demand response, electricity demand acts as a source of flexibility, whose characteristics depend on the capabilities of electrical devices to alter the electricity consumption. Demand response can take the form of load curtailment or load shifting. While load curtailment represents an overall reduction of electricity demand, load shifting implies that a certain over-consumption results in a subsequent decrease in consumption and vice versa.

In this setting, industrial loads can play a key role to provide demand response. This type of loads is often based on energy intensive processes; therefore, the electricity cost constitutes a significant portion of the total operation cost. Moreover, industrial loads consist of a significant share of the global electricity demand. According to IEA, the share of industrial load worldwide is 35% in 2018[230]. According to China Electricity Council, the electricity consumption in mining and manufacturing industries accounts for 54% of electricity consumption in China in 2018[231]. For this reason, leveraging the flexibility of industrial loads will unlock a high amount of flexibility for power systems to cope with the variable electricity generation from renewable energy sources.

The management of aluminum smelters is an interesting example to achieve flexibility from industrial loads.[232] Aluminum smelting is an energy-intensive electrolytic process widely used to produce aluminum. The cost of electricity constitutes a large share of the production cost. At the same time, the smelting process is able to change its power consumption within an allowed range both accurately and quickly, without affecting the production quality. Hence, aluminum smelters, given correct economic incentives, have both motivation and ability to participate in flexibility provision.[233]

To study aluminum smelters' behaviour the following assumptions are made:

- Aluminum smelters provide up to ±10% of their installed capacity as flexibility;
- Charging and/or discharging of aluminum smelters as virtual batteries requires up to 24 hours;
- The demand response activation leads to a penalization cost of 325 RMB/MWh;
- The default electricity consumption profile of aluminum smelters is represented as constant during the day;
- During the Spring Festival (between January and February), aluminum smelters do not operate for three weeks due to vacation period.

The modelling of aluminum smelters' dynamics is included in both Below 2 °C Scenario and Stated Policies Scenario, where the modelling and assumptions are maintained consistent in the two scenarios. This is because the constraints and assumptions made have technical reasons and do not depend on the scenarios.

Figure 9-26 shows that the provinces with the highest shares of electricity consumption for aluminum smelters include Shandong (20.6%), Xinjiang (18.2%), Henan (11.6%) and Qinghai (7.4%).

Figure 9-26: Electricity demand for aluminum smelters in 2018

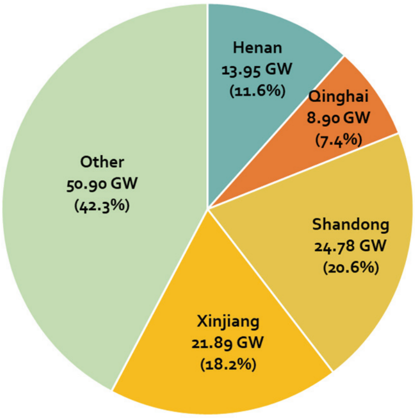


Figure 9-27 shows that the amount of aluminum produced by the industry will increase. The amount of aluminum produced in China in 2018 was of 38.4 million metric tons. For Stated Policies Scenario, in 2050 it will reach 50.5 million metric tons, an increase of 31%. Also, the amount of electrolytic aluminum will decrease, and consists of 42% of the total aluminum production in 2050. The 2050 aluminum production is 27.8 million tons of electrolytic aluminum and 22.8 million tons of recycled aluminum.

Figure 9-27: 2018-2050 Aluminum production in China for Stated Policies Scenario

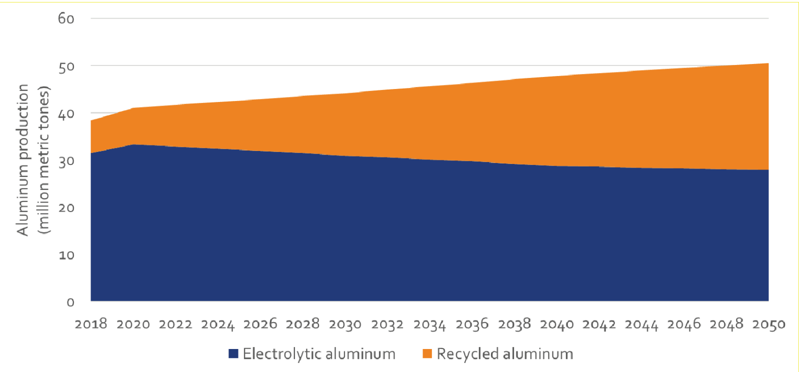
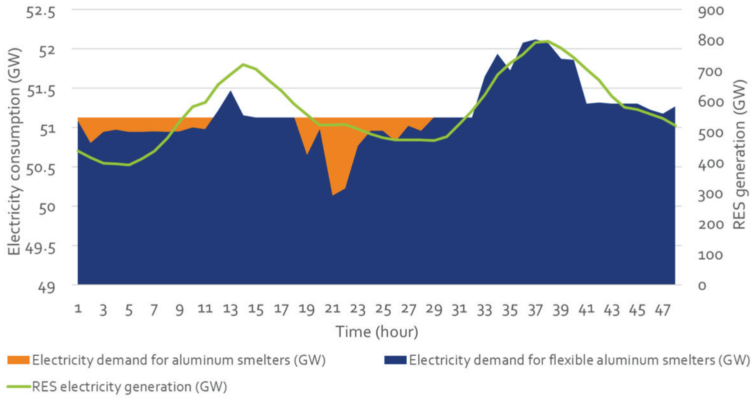


Figure 9-28 shows how the Chinese electricity demand for aluminum smelters changes according to the renewable energy generation in 2025 according to Below 2 °C Scenario. Specifically, the inflexible consumption is originally 51.1 GW. However, by adopting a flexible consumption management for aluminum smelters, the consumption increases to 52 GW when a peak of renewable energy generation occurs. Vice versa, it decreases to 50 GW, when there is a lack of renewable energy generation. Fig. 9-29 shows similar pattern in Xinjiang as an example.

Figure 9-28: 2025 Electricity consumption for aluminum smelters and renewable energy generation in China for Below 2 °C Scenario



The correlation between electricity consumption and renewable energy generation is driven by lower marginal electricity cost provided by renewable energy, making consumption more attractive. In Fig. 9-30, such relation is shown. Specifically, the marginal electricity price varies between 0.13 and 0.32 RMB/kWh, where the flexible electricity consumption inversely follows the price trend.

Figure 9-29: 2025 Electricity consumption for aluminum smelters and renewable energy generation in Xinjiang for Below 2 °C Scenario

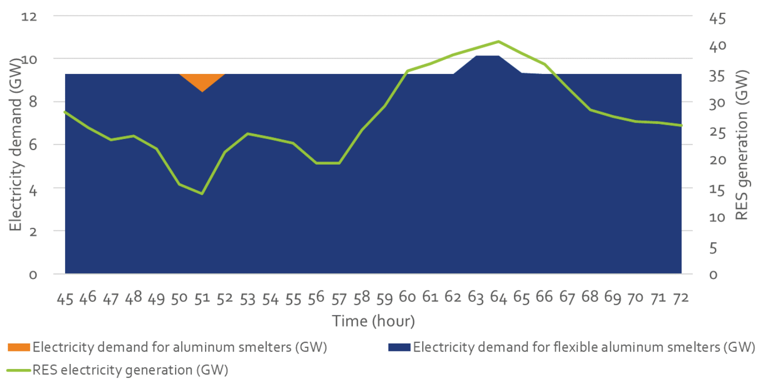
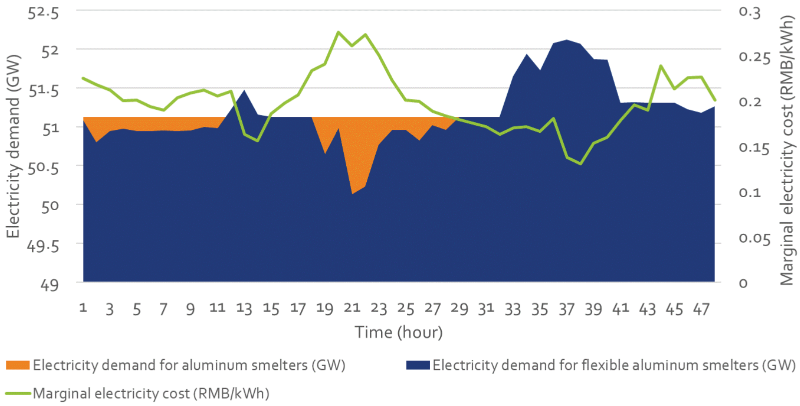
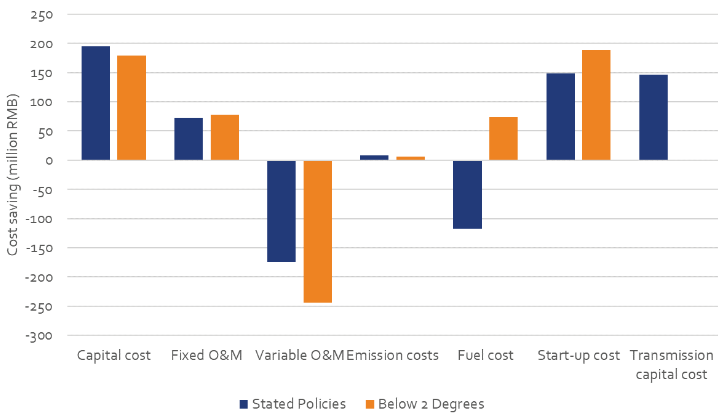


Figure 9-30: 2025 Electricity consumption for aluminum smelters and marginal electricity cost in China for Below 2 °C Scenario



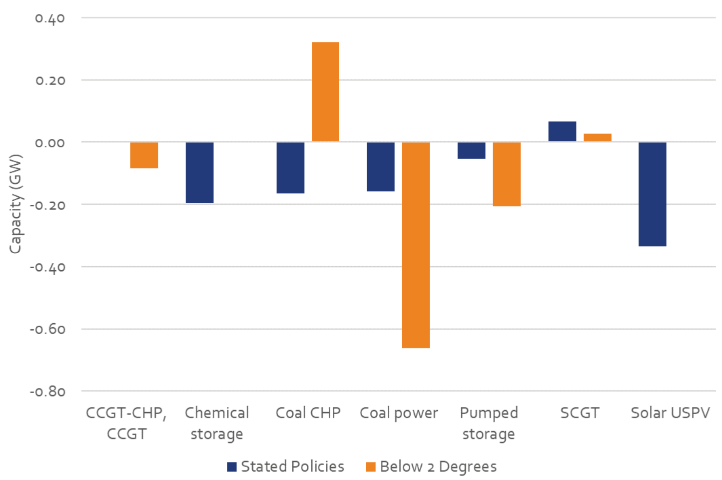
From an economic perspective, leveraging flexibility from aluminum smelters emerges as economically attractive solution, which will lead to a yearly cost savings of 278.6 million RMB for Stated Policies Scenario and 281.0 million RMB for Below 2 °C Scenario in 2025. In Figure 9-31, the various cost savings components are reported. The main saving components include reduced unit capital costs (195.0 million RMB for Stated Policies Scenario and 178.8 million RMB for Below 2 °C Scenario), which mainly refer to storage units, and start-ups cost (149.0 million RMB for Stated Policies Scenario and 188.2 million RMB for Below 2 °C Scenario), which refer to power generation and storage units. Moreover, leveraging flexibility from aluminum smelters leads to a saving of 7.8 million RMB for emission costs in Stated Policies Scenario (6.2 million RMB in Below 2 °C Scenario). For Stated Policies Scenario, the reduced transmission capital cost also leads to a saving of 146.1 million RMB due to avoided transmission expansion. On the other hand, the engagement of consumption flexibility leads to increasing variable O&M costs, which include flexibility activation costs.

Figure 9-31: 2025 cost savings from consumption flexibility of aluminum smelters in China



Flexibility provided by aluminum smelters can substitute the needs for additional storage, especially when the cost of chemical storage is more than that of activating demand response.Figure 9-32 shows that technology capacity installation overall decreases by 0.83 GW for Stated Policies Scenario and 0.59 GW for Below 2 °C Scenario. Coal power decreases by 160 MW for Below 2 °C Scenario and 660 MW for Stated Policies Scenario. The decrease of coal power in Stated Policies Scenario is partly compensated by coal CHP by 320 MW. In Below 2 °C Scenario, chemical storage is reduced by 200 MW while solar USPV decreases by 330 MW. Overall, it emerges that storage capacity is reduced by 400 MW of thermal capacity in Below 2 °C Scenario (200 MW for Stated Policies Scenario); chemical storage of 200 MW for Stated Policies Scenario; 50 MW for Stated Policies Scenario and 200 MW for Below 2 °C Scenario of pumped storage due to the introduction of aluminum smelters flexibility.

Figure 9-32: 2025 Additional (-reduced) capacity from using aluminum smelters' flexibility in China



To foster the adoption of demand response from industry, it is fundamental that potential barriers are properly handled. [234] Specifically, it needs to be created adequate compensation for flexibility provision to reflect its system value. Demand response requires a transparent wholesale market to provide price signals to short-term flexibility provision. An entity to aggregate loads (i.e., load aggregator) can be introduced, to simplify the communication and management of flexible consumers. A solid business model must be ensured for load aggregators to support the adoption of demand response.

10. Energy Sector Development

The overall energy system development and roadmap are an aggregation of key development trends and measures to be taken in key subsectors, including power, heating, industry, transport etc. The detailed energy needs of consuming sectors and their different modes of consumption, the state of consuming devices etc, are aggregated to produce key indicators for the overall energy sector such as final and primary energy consumption, energy mix and societal emissions.

From a policy planning perspective, in China, policy guidance is set in the form of top-down targets and objectives. Such objectives can be broken down to sub-targets and finally implemented through measures for specific energy systems, economic subsectors and industries.

This chapter presents the scenarios' overall energy system developments to convey the metrics achieved in the energy system, as the aggregate effect of the evolutions prescribed in the roadmaps for the different sectors in the previous chapters. This forms the basis for establishing an overall roadmap for the energy sector. We emphasise the cross-cutting trends and developments, their interdependency and the objectives energy sector-related macro with focus on the 14th five-year plan; and provide guidance for the two following five-year plan periods leading to the end of China's next era of economic and social development, 2035.

10.1 Energy sector developments

The high-level indicators of the two scenarios are presented on Table 10-1 and Table 10-2, aggregating the combined energy system effects of the detailed roadmaps described in prior chapters.

Table 10-1: Key figures in the energy sector development in the Stated Policies scenario

		2018	2020	2025	2030	2035	2050
Energy basis							
Total Primary Energy Supply (TPES)	Mtce	4 346	4 476	4 730	4 718	4 412	3 673
Total Final energy consumption (TFE(	Mtce	3 165	3 251	3 427	3 510	3 463	3 158
CO_2 emission	Mton	9 526	9 337	9 077	8 223	6 640	3 586
Non-fossil fuel share of TPES (NFF)	%	10%	14%	19%	24%	32%	53%
RE share of TPES	%	8%	11%	15%	20%	27%	46%
Coal share of TPES	%	61%	56%	47%	40%	30%	16%
Coal share of TFEC	%	33%	29%	21%	15%	11%	6%
Gas share of TPES	%	8%	10%	14%	16%	20%	21%
Oil share of TPES	%	20%	20%	20%	19%	17%	9%
Electrification rate	%	26%	29%	34%	39%	43%	54%
Coal substitution method							
Total Primary Energy Supply (TPES)	Mtce	4 685	4 892	5 318	5 599	5 610	5 413
Non-fossil fuel share of TPES (NFF)	%	17%	21%	28%	36%	47%	68%
RE share of TPES	%	15%	18%	24%	32%	42%	63%

Table 10-2: Key figures in the energy sector development in the Below 2 °C scenario

		2018	2020	2025	2030	2035	2050
Energy basis							
Total Primary Energy Supply (TPES)	Mtce	4 346	4 476	4 610	4 432	4 025	3 536
Total Final energy consumption (TFEC)	Mtce	3 165	3 252	3 396	3 438	3 349	3 046
CO_2 emission	Mton	9 525	9 337	8 804	7 184	5 079	2 532
Non-fossil fuel share of TPES (NFF)	%	10%	14%	19%	29%	42%	65%
RE share of TPES	%	8%	11%	16%	25%	37%	58%
Coal share of TPES	%	61%	56%	47%	36%	23%	11%
Coal share of TFEC	%	33%	29%	20%	14%	10%	4%
Gas share of TPES	%	8%	10%	13%	15%	18%	16%
Oil share of TPES	%	20%	20%	21%	19%	16%	7%
Electrification rate	%	26%	29%	35%	41%	48%	66%
Coal substitution method							
Total Primary Energy Supply (TPES)	Mtce	4 684	4 891	5 253	5 549	5 603	5 766
Non-fossil fuel share of TPES (NFF)	%	17%	21%	29%	44%	59%	79%
RE share of TPES	%	15%	18%	26%	40%	55%	74%

Primary energy consumption (in coal substitution terms) grows in the scenarios from 4680 mtce in 2018 to 4890 mtce in 2020. In the 14th FYP period until 2025, total primary energy consumption expands to around 5300 mtce. It stabilises around 5600 in the 15th and 16th five-year-plans. By 2050, the total primary energy consumption decreases to 5410 mtce in the Stated Policies scenario, while it increases to 5760 in the Below 2 °C scenario. The coal substitution method is the traditionally used approach to account for the primary energy content of renewable electricity in China. This is a logical consequence of China's traditionally coal dominated energy system. However, as the energy system evolves, such a measure becomes less appropriate. Measured by the statistical energy content method, primary energy consumption peaks at around 4760 mtce in 2027 in the Stated Policies scenario and at 4610 mtce by 2025 in the Below 2 °C scenario.

Final energy consumption grows from 3250 in 2020 to peak around 3500 mtce in 2030 in both scenarios. The overall electrification rate increases from 26% in 2018 to 35%, 40% and 42% in 2025, 2030 and 2035 respectively in the Stated policies scenario. In the Below 2 °C scenario, 35%, 41% and 47% is the overall electrification rate in 2025, 2030 and 2035.

The non-fossil share of the primary energy consumption exceeds 21% in the 14th five-year plan, achieving the current target of 20% by 2030 ahead of time.

Final energy demand mix

The Stated Policies scenario sees the share of coal in final energy consumption decrease from 33% in 2018 to 11% in 2035 in the Stated Development scenario, and further to 10% in the Below 2 °C scenario. Electricity as a share of final consumption increases from 26% in 2018 to 39% in the Stated policies scenario and to 41% in the Below 2 °C scenario by 2035. Natural gas increases its role in the final energy consumption from 8% in 2018, to 20% in the Stated Policies scenario and slightly more modest 18% in the Below 2 °C scenario by 2035. Biofuel blends in the transport sector increase in absolute terms but retain their proportional role in the final energy mix, while other oil products decline from 11% in 2018 to 7% in 2035 in the final energy consumption.

By 2035, hydrogen, produced with electricity, accounts for 0.6 and 2.2% of the final energy consumption in the two scenarios respectively.

Figure 10-1: The development of final energy consumption (Mtce) by energy type from 2018-2050 in the Stated Policies scenario

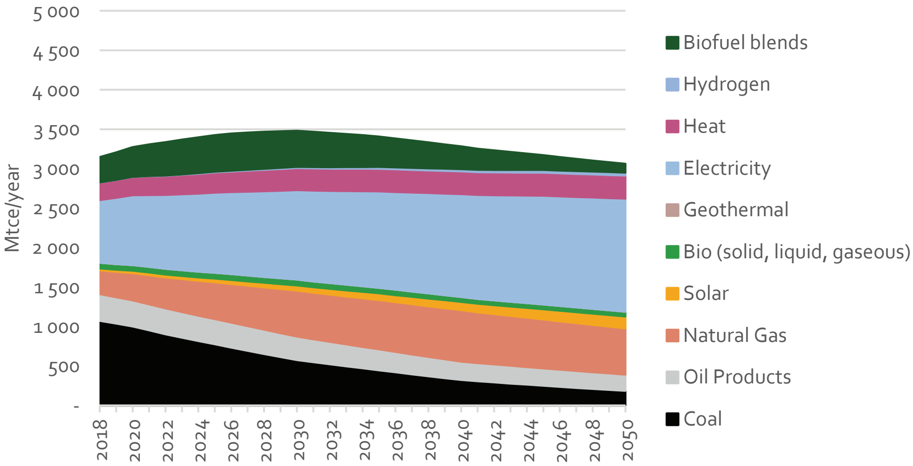
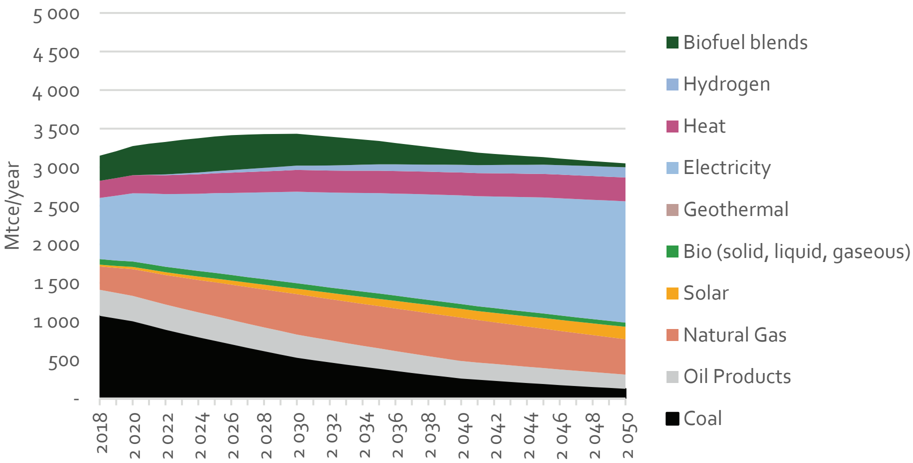


Figure 10-2: The development of final energy consumption (Mtce) by energy type from 2018-2050 in the Below 2 °C scenario



Primary energy demand

The Stated Policies scenarios sees a decrease in the coal share of the primary energy demand from 61% in 2018 to 30% in 2035, and comparatively 23% in 2035 for the Below 2°C scenario. Both scenarios project a similar increase in relative natural gas demand, being at 8% in 2018 and increasing towards 2035 to 20% in the Stated Policies scenario and 18% in the Below 2°C scenario. The drastic projected change from fossil fuel combustion to renewable generation in primary energy demand is very apparent in the years between

2025-2035. The Stated Policies scenario sees a decrease in relative primary energy supply from fossil fuels throughout this period by 14 percentage points, whereas the Below 2°C scenario sees a decrease of 23 percentage points. The share of energy supplied from renewable energy sources increases from 8% in 2018 to 27% in 2035 for the Stated Policies scenario, and similarly, 37% for the Below 2°C scenario.

Figure 10-3: The development of primary energy consumption (Mtce) by energy type from 2018-2050 in the Stated Policies scenario

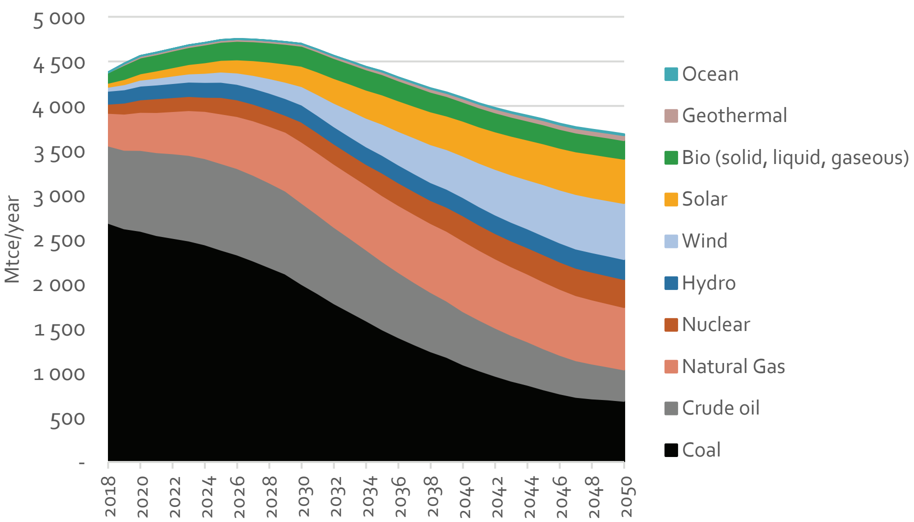
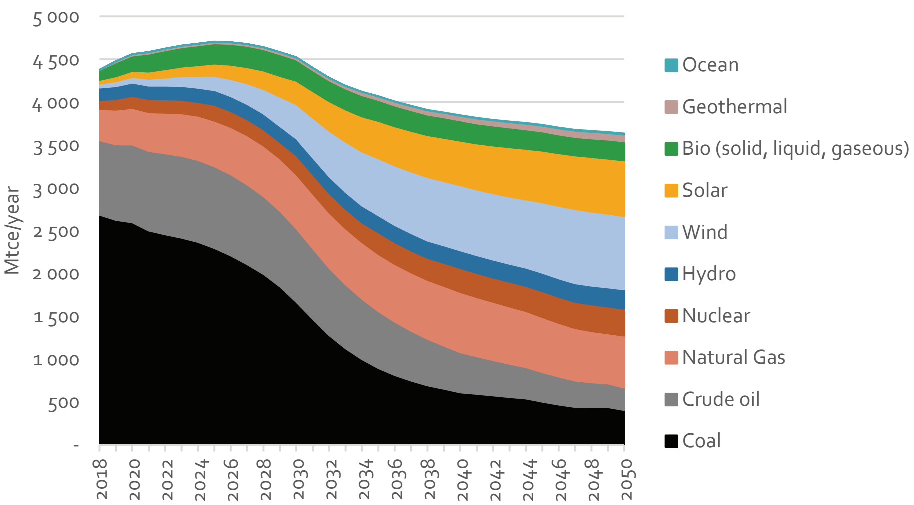


Figure 10-4: The development of primary energy consumption (Mtce) by energy type from 2018-2050 in the Below 2 °C scenario



Energy sector CO2-emissions

The scenarios show that energy-related CO2 emissions in China should have plateaued in 2050. From here on, new energy consumption should be efficient, clean and low carbon. Moreover, the energy sector transformation must carve into existing consumption patterns, replace existing devices and ensure that energy capital stock replacements are made with clean and low-carbon investments rather than reinvestments in fossil-fuel reliant devices and processes. The cumulative CO_2 emissions in the Stated Policies reaches a total of 230 billion tons in the period between 2018 and 2050. This is a total of 18% higher than the corresponding 195 billion tons in the Below 2 °C scenario.

Figure 10-5: Energy sector CO2-emissions in the two scenarios (million tons/year)

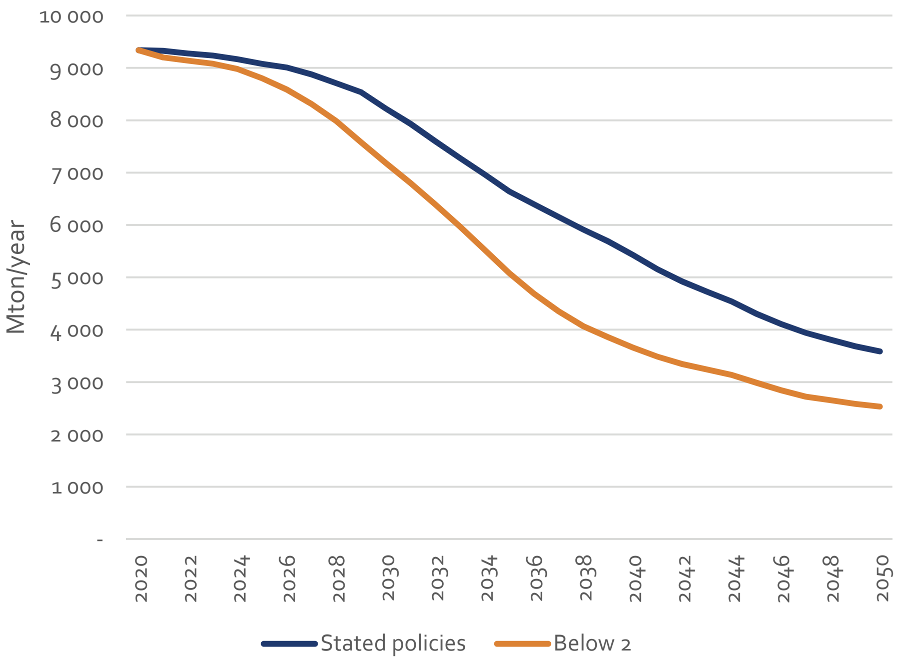


Figure 10-6: Kaya identity in the Stated Policies scenarios relative to 2005

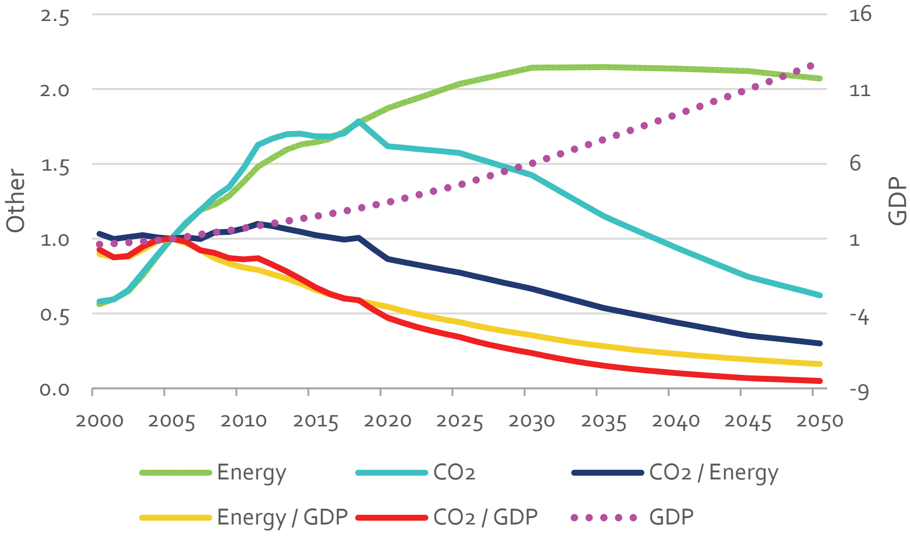
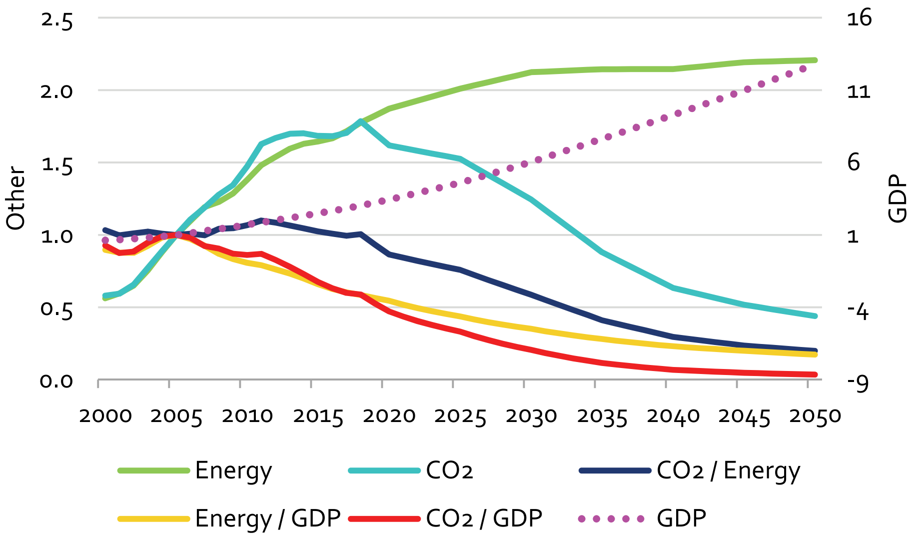


Figure 10-7: Kaya identity in the Below 2 °C scenario relative to 2005



The two scenarios offer sustained economic growth and sustained stable supply of energy to underpin this growth, through the stabilisation of the energy consumption level and rapid decarbonisation of the energy supply. In particular, the Kaya identity charts show that, although GDP-growth is expected to continue at a high rate until 2050 in both scenarios, the reduction in carbon intensity of GDP more than offsets this. Being 0.59 in

2018, it reaches around 0.04 in 2050 for both scenarios. Moreover, the carbon footprint of energy also decreases, going from 1.01 in 2018 to 0.57 in the Stated Policies scenario and 0.43 in the Below 2°C scenario.

10.2 Energy Sector Roadmap

The *Energy Consumption Revolution* is an Energy Efficiency Revolution with the key feature of deep electrification. The *Energy Supply Revolution* is a Renewable Energy Revolution, with strong emphasis on renewable electricity. Renewable electricity is the most cost-effective large-scale decarbonisation approach. In order to ensure that renewable electricity by 2035 is at the core of the energy system, it is important that steps toward such objective are taken in the 14th FYP period. Such steps must be followed up in the 15th and 16th five-year plans.

Sustainable economic growth while building the ecological civilization

In our scenarios, the 14th FYP is expected to grow the economy by 34% in real terms from 2020-2025. Meanwhile, coal consumption declines to 11%, the War on pollution must be won, primary energy consumption growth should be limited to 6% (9% by coal substitution). Energy consumption intensity of the economy should be reduced by 21% and energy CO2 intensity should be reduced by 27% - a total reduction of CO2 intensity of 65% relative to 2005.

The subsequent 15th and 16th FYP should grow the economy by 31% and further 26%, respectively. To achieve this development during the most critical era of China's economic and societal development and most critical era of energy transition, the design of and objectives for the next three five-year-plans of China must take concrete steps at each stage.

Figure 10-8: Shift in primary energy consumption mix during 14th FYP (Below 2°C)[235]

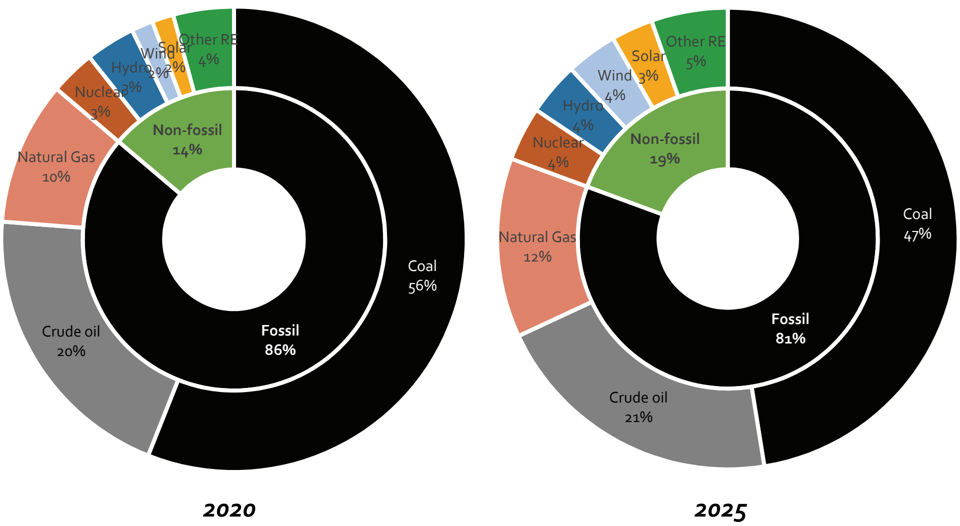
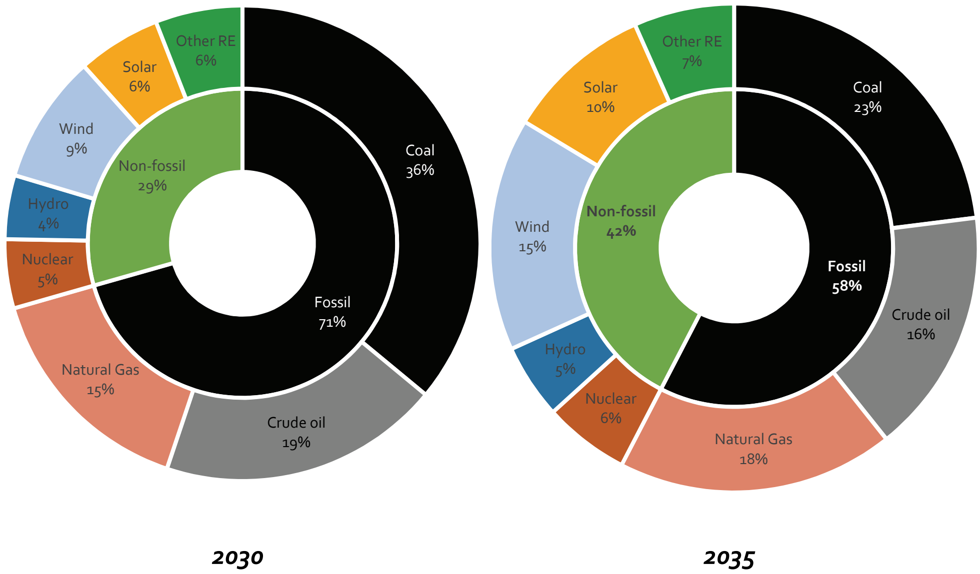


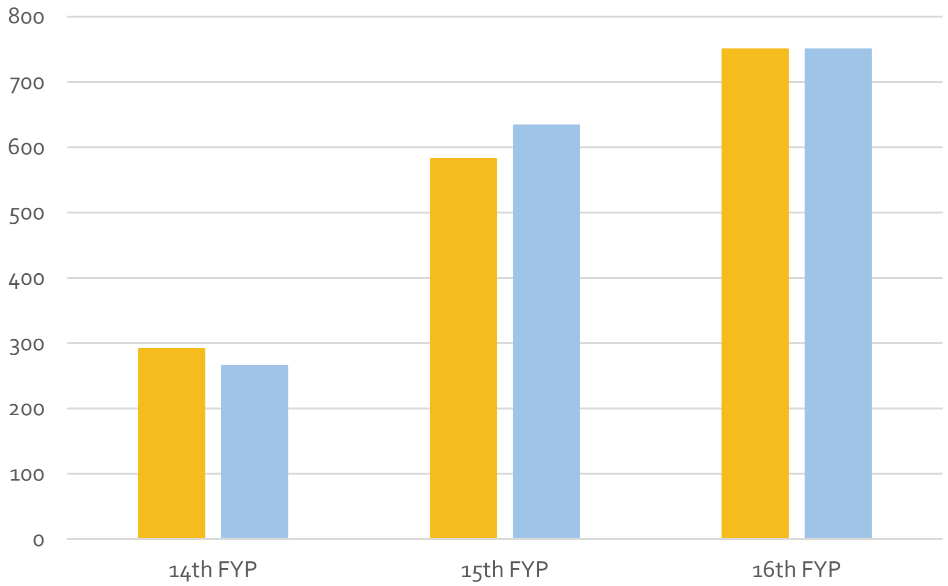
Figure 10-9: Further switch in primary energy mix during 15th and 16th FYP (Below 2°C)[236]



Decarbonisation of electricity supply

In the 14th FYP, the key challenge is increasing the pace of power sector decarbonisation. Electrification with decarbonised electricity is the core of CREO's Energy Transition Strategy. If decarbonisation of electricity supply does not accelerate, the positive impact to climate and pollution levels from electrification will not materialise.

Figure 10-10: Wind and solar installations under by five-year-plans (GW)



In the 14th FYP period, the pace of wind power installations should average 53 GW per year, while the average yearly solar installations should be 58 GW. In the 15th FYP period new wind installations should average 127 GW per year and solar achieve 116 GW per year. Annual installations should peak at around 150 GW per year in the 16th FYP period. *Note: this is a hard limit set in the modelling, to avoid an over scaling of the wind and solar industries, as the need for annual installations will decline after 2035. From a pure energy system economic point of view the installation levels could be higher in the 16th FYP period.*

For renewable electricity deployment the next 3 five-year plans must a pattern of three steps:

1. 14th FYP: Industry scale-up
2. 15th FYP: Establish
3. 16th FYP: Revolutionise

The recommendations for 14th FYP deployment of renewables is indicated on Table 10-3. For the power sector decarbonisation, the critical targets to be achieved by 2025, is that wind power cumulative installed capacity exceeds 500 GW, contributing with potential annual generation of approximately 1350 TWh of electricity. Moreover, solar power cumulated installed capacity should reach 530 GW, and contributed with electricity generation of around 690 TWh.

The 14th FYP period will be a critical phase for renewable energy installations, where in tandem with scaling-up the industry and annual deployment levels, investors and asset owners must learn to navigate the uncertainties of simultaneous reforms. RE investments must wean off the comfortable business model of fixed price subsidies and navigate the emergence of spot-markets as well as medium- to long-term contracting markets as these are developed. Investors and asset owners shall have confidence that they are able to capture adequate prices for their electricity generation, and that they will not be curtailed, while being exposed to the market. There must be evidence that system flexibility develops as needed; alternatively, they must develop more complex business models bundling VRE sources with own investments in flexibility and storage. The market must respond timely to the development of the demand for green, clean or non-fossil electricity – the pull from demand and the requirements from regulation. Finally, there must be confidence that, despite a slowing energy consumption growth resulting from energy efficiency and economic restructuring, there will be increased electrification, and that the authorities will abstain from distorting the markets by supporting competing power offerings from coal and gas and depress the prices.

To support an orderly development approach, the 14th FYP should prioritized fluctuating generation capacity by a balanced mechanism, giving priority to developing industries and supply chains near consumption centres and balancing resources. This includes strong focus on the development of wind offshore, opening further for distributed siting of wind projects, as well as improving conditions for distributed generation from solar.

Table 10-3: Suggested targets for 14th, 15th and 16th FYP period based on the Below 2 °C scenario

Category	Indicator	14th	15th	16th
1. Renewable power generation capacity target (GW)	**Total**	**1481**	**2718**	**4108**
	1. Hydropower	386	438	455
	2. Wind power	507	1109	1763
	3. Solar photovoltaic	532	1109	1825
	4. Solar thermal power generation	4	9	11
	5. Biomass power generation	51	54	54
2. Renewable electricity generation target (TWh)	**Total**	**3662**	**6416**	**9308**
	1. Hydropower	1397	1.576	1625
	2. Wind power	1347	3160	5053
	3. Solar photovoltaic	694	1448	2393
	4. Solar thermal power generation	11	22	28
	5. Biomass power generation	214	210	210

In the 15th FYP, the pace of RE capacity additions moves towards the peak, while growth rates in power consumption, drops to 3.5% p.a. on average. The 15th FYP must thread the needle of building the capacity for a long-term sustainable renewable energy industry. The 16th FYP will be the period of disruptive transformation. We are past the economic tipping points with significant impact to asset utilisations. Wind and solar annual installations should reach their peak at around ~150 GW/year and new electricity storage should be coming online at the pace of 30 GW per year. Utilisation rates of fossil-thermal plants shall decline significantly – where, in our calculations, remaining coal plants should drop below 2,500 annual FHL and gas plants output should be reduced by approx. 10% over the five-year period. Though this has not been directly included in the scenarios, a significant focus on strategic plant closures should be considered.

Developing a coupled energy system with electrification as the crux

The 14th FYP should include targets and measures to support technologies an incentive to unleash the benefits of an efficient power and district heating coupling. The stock of individual heat pumps should be increasing and displace individual coal boilers and stoves. The number of EVs should increase to almost 33 million by 2025, and around 14% of the vehicle stock should be new energy vehicles (NEVS) including electric, hydrogen and plugin hybrids. For EVs, this shall be accompanied by charging infrastructure, with around 1 normal charging stations for every 10 EV's and around 1 fast charging stations per 100 EVs. Programmes and/or retail tariffs for EV charging should expose users to changing prices, such that smart charging is motivated.

Electrification should move to exceed 42% of the final energy consumption in industry, and industries should be exposed to fluctuating market prices, and motivated towards providing cost-efficient demand respond. Key energy intensive industries should be at the forefront. Scrap-based electric arc furnace steel should reach 30-32% by 2025.

By the end of the 16th FYP, the penetration levels of variable renewable energy will be high, and the availability of traditional thermal assets for maintaining the system balance including ancillary services shall reduce. Smart energy services, demand response from industrial and residential loads and electric vehicles must be deployed at scale. The district heating sector has achieved the tipping point, where large-scale replacements of thermal heating capacity, including CHPs are being replaced/supplemented by power-to-heat technologies. The energy internet becomes a reality, with data and digitisation supporting the timing, scheduling, adjustments and power based on a comprehensive system of data on loads, prices, assets locations. This becomes possible with the introduction of smart meters as well as home energy management systems, etc.

Strict coal controls to halve consumption by 2035

The 13th five-year plan for energy development set the binding target that coal's proportion of the primary energy consumption should be reduced from 65% in 2015 to 58% in 2020 – a drop of 6 percentages points over the five-year period.

In the 14th FYP, the coal consumption should be reduced by 10%. The 15th FYP should implement further 24% reduction, and in the 16th five-year plan period the reduction should be 37%. Thereby the coal share of primary energy consumption is reduced to 47%, 36% and 23% by the end of the 14th, 15th and 16th five-year plans respectively.

While in the long-run, the expanded national ETS system could be the preferred mode of coal and carbon containment, administrative measures are needed in the short-term. In the 15th FYP, a de facto ban on new coal should be in place. The direction is critical to avoid exacerbating the issue of stranded costs in the coal industry.

Addressing economic woes of fossil-dependent industries and local economies

The process of energy system transformation will adversely affect established industries. Carefully management of the transformation includes promotion of economic and social policies targeted at areas, where the local economy is currently heavily dependent on coal.

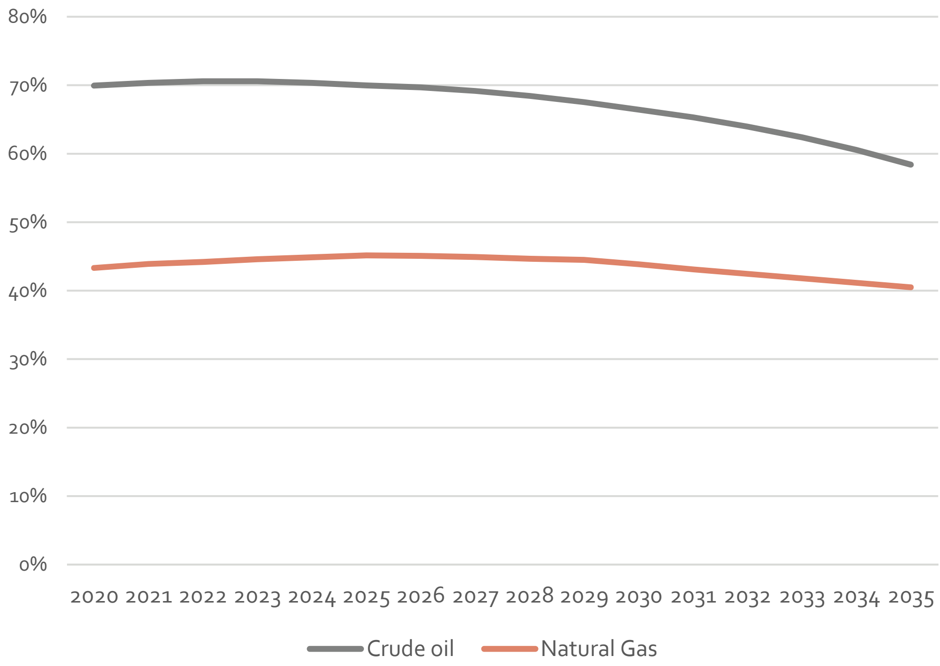
In the 14th FYP it is imperative that industries are not allowed to exacerbate the long-term challenges. Furthermore, in this period *notions of need* for coal or fossil-fuel use in the short-term should not be entertained to justify further investments in industries, which need to be replaced in the long-term. The power sector, for instance, risks adding stranded costs of 425-925 billion RMB unless growth in coal power capacity is arrested in this period, according to sensitivity analyses conducted with the power sector model (assuming coal capacity expands to 1.25-1.4 TW).

In the 14th FYP, the efforts to promote thermal power plant flexibility should be extended primarily to support the retrofitting of existing assets with reasonable efficiency and not to support the development of new plants. This process should not serve to expand the generation of coal plants; it should ensure that coal plants are able to complement the expanding renewable sources in the system. Moreover, it should ensure that the value of these services is compensated at fair market value. In those regions requiring heating, it should be ensured that CHP plants can be used instead of coal-fired boilers and co-generate heat with electricity, with generation happening when the power system needs capacity, and that heat storages, rather than forced CHP generation, can guarantee the continuity of heating supply.

Preserving energy security by the energy transition

The energy transition must ensure that safe and stable energy fuels the economy in the next era of economic development. The rapid growth of oil consumption is potentially destabilising, as oil imports account for increasing percentages of the country's supply.

Figure 10-11: Import shares of oil and natural gas in the Below 2 °C scenario



For this reason, it is fundamental to shift the industry away from oil and gas, promoting the use of indigenous sources- particularly renewables. Specifically, the stock for new energy vehicles (i.e., plug-in hybrid, hydrogen fuel cell and electric) is expected to reach 50.23 million vehicles in the 14th FYP, 191.35 in the 15th FYP and 420.33 in the 16th FYP. Consequently, the stock of hybrid, CNG, diesel and petrol fuelled cars is expected to fall, reaching 0.34 million vehicles in the 14th FYP, -13.07 in the 15th FYP and -44.83 in the 15th FYP.

The efforts to expand indigenous natural gas supplies are merited and necessary, provided that environmental safeguards are forcefully upheld. China must avoid that the economy is significantly dependent on imported foreign fuel. Natural gas imports, which grow by almost 70%, see an estimated increase in the import share by at least 6 %-points during the 14th five-year plan. Hereafter, the combination of increased domestic production and a slowdown in growth of gas consumption in favour of other clean energy sources, implies that the import share of natural gas can decline in the 15th FYP. By 2035, the import share of oil and natural gas can be lower than today, as a result of the energy transition.

The expansion natural gas supplies by subsidizing natural gas consumption as a short-term mean of addressing air pollution comes at an economic cost. Moreover, the Chinese economy is significantly dependent on imported foreign fuel; in this matter, renewable energy industry can deliver superior results, with less exposure to supply security risks.

In the power sector, for example, an increased role for natural gas of 10% relative to the CREO scenario, would lead to additional costs of 60 bn RMB.

Strengthened energy efficiency targets for the next phase of energy transition

The importance of energy efficiency in the energy transition cannot be overstated. The rapid pace required for scaling-up clean energy investments on the supply side is only sufficient, given that energy consumption is significantly decoupled from the economic growth targets.

In the 14th FYP energy efficiency measures must be defined such that the primary energy consumption per unit of GDP should decline by at least 19%. The measures shall support the transitioning of consumption from their current energy carriers towards electricity. Final energy consumption should remain below 3400 Mtce/year and primary energy consumption not grow above 4610 Mtce.

In the 14th FYP, increase in energy efficiency must be achieved:

- By promoting efficient processes. For example, in industry, steelmaking from electric arc furnaces (EAF) is assumed to contribute up to 19% in steelmaking production.
- Through technology improvement. For example, in building, electric heaters are expected to reach an efficiency of 96.9%.
- By leveraging DH, which is expected to cover 69.2% of residential urban heating.

Energy efficiency shall take place both in the point of energy use and in the supply-chain. It can be achieved through better insulation and technology improvement in buildings (e.g., electric heaters will reach an efficiency of 98.1% by 16th FYP) as well as the promotion of efficient processes in industry (e.g., in steelmaking, EAF process will contribute up to 29% in steelmaking production by 16th FYP). Furthermore, the energy efficiency benefit of renewables should be recognized in setting targets for primary energy consumption. Until 2035, the final energy consumption increases to around 3,350 Mtce/year, while primary energy consumption should be contained below 4025 Mtce/year.

Breaking the curve of energy related CO2-emissions

Despite an uncertain, and at times tense, geopolitical environment, there is strong active cooperation on energy and climate issues, which benefits all parties.

Carbon intensity levels should be reduced in the 14th five-year plan by 27% to 67 g/RMB – a cumulative reduction of 66% since 2005 (in real terms).

In the 14th five-year plan, the carbon market should be reformed to include self-adjusting mechanisms, such as a flexible cap, floor price, and stability reserve, to prevent a collapse in carbon prices leading to undesired investment signals in favour of high-carbon investments. The carbon quota allocation scheme must be adjusted to not provide indirect subsidy for (efficient) coal-fired generation over clean energy sources.

Part4:
Policy Action suggestions

11. Suggestions for Policy Actions During the 14th Five-Year Plan

China's renewable energy sector, especially wind and solar power, has developed rapidly in terms of technology, industry, and markets. Large-scale manufacturing, new technologies, and improved business models have reduced the cost for wind and solar substantially. In 2018, commercial renewable energy accounted for 12.5% of primary energy consumption, laying a foundation for China's energy revolution and transition to clean energy, and contributing to global development of renewable and low-carbon energy.

China has led new energy development to promote the revolution of energy production and consumption. This energy revolution means continuously increasing the supply of clean and green energy and constantly increasing its proportion in energy production and consumption. China has set the objective that non-fossil energy should account for 15% of primary energy consumption by 2020 and 20% by 2030. Such targets are not only a guide for future energy transformation, but also a clear task for the development of renewable energy in the short and medium term.

Looking ahead, the period between 2019 and 2025 will be critical for China's energy transformation, which will be supported by the development of renewable energy. In order to realize the national objective of non-fossil energy accounting for 20% of the primary energy consumption and non-fossil energy power accounting for 50% of the total electricity consumption by 2030, renewable energy industrial development and supporting policies and markets are strategic. However, the uncertainty over how the renewable market will develop during the 14th Five-Year Plan period (2021-2025) makes policy and market design complex and challenging. This chapter mainly analyses the environment and key policy issues in the development of renewable energy during the 14th Five-Year Plan period and puts forward policy and institutional recommendations based on a study of various scenarios.

11.1 Renewable energy power

Many RE feed-in tariffs will phase out shortly

Early in the 14th Five-Year Plan period, the feed-in tariffs for onshore wind and PV generation will be withdrawn since these industries have become mature with rapid market development and large manufacturing scale. In the 13th Five-Year Plans for energy, renewable energy, wind energy and solar energy, the Chinese government set objective that wind power should compete with coal power on the same basis and PV should reach price parity with government-set coal tariffs by 2020. Since 2016, China has launched a series of measures and actions to reduce the cost and tariffs for mature renewable energy sources such as wind and PV. China has demonstration projects for wind and PV plants that produce energy for at or below local coal tariffs. The government has introduced auctions for wind power and PV. In addition, the government has launched market-based trading for distributed generation and put forward 12 measures to reduce the financial burden of renewable energy enterprises. Finally, to improve renewable integration, the government implemented a renewable energy electricity consumption guarantee as well as a voluntary green certificate system. In 2019, all new wind power projects were fully determined via competitive allocation to determine project owners and feed-in tariffs. For PV, in addition to household PV and PV poverty alleviation projects, China implemented auctions for determining PV construction projects according to the total amount of subsidies, held competitive allocations locally, established a unified national project ranking, and formulated eight supporting policies. In 2019, the weighted average difference between the tariffs for coal-fired power generation and onshore wind is RMB 0.1/kWh and RMB 0.14/kWh for PV. Considering the implementation of competitive allocation of onshore wind power, the actual subsidy level will be even lower. According to the latest wind power tariff policy, the feed-in tariff for newly built onshore wind power projects will be completely withdrawn by 2021. In 2019, the average subsidy level of PV auction projects is only RMB 0.065/kWh. According to the industry's expectations on technological progress and cost changes, PV generation is expected to enter the stage of parity with current coal tariffs in the early period of the 14th Five-Year Plan.

The 14th Five-Year Plan period is key to reform of renewable energy policy. For over a decade, China has implemented a feed-in tariff and subsidy compensation mechanism to support the renewable energy directly, but policy supports will shift during the 14th Five-Year Plan period. New support policies will be more innovative, while continuing to both support prior renewable energy systems, as well as supporting and guiding the renewable energy industry's development. These changes coincide with the reform of the electric power wholesale market, which will both come to greater fulfilment in the 14th Five-Year Plan period. All involve various, multi-dimensional and uncertain factors in the design and implementation of renewable energy power policy support.

Renewable energy participates in the power market

Market design should include gradual and conditional participation of renewable energy in the market. Renewable energy's participation in the power market is not only a future trend, but also a gradual process from the perspectives of both international experience and the direction of China's power system reform. For example, China has just started establishing electricity spot markets. At the end of June 2019, the first batch of eight spot markets entered the stage of trial operation. The Southern Electricity Spot Market took the lead in implementing electricity spot market settlement in May 2019. As yet, there is no timetable for other provinces not on the first list, and as a result, the process and designs of spot markets may vary from region to region. In the future, renewable energy's participation in the spot market (among other electricity markets) should gradually be extended to different regions.

In the early stage, renewable energy power should participate in the power markets by bidding a production curve without quoting a price, and take priority in market clearing as a price taker, to enable priority for renewable consumption. When the spot market is mature and stable, newly added renewable energy projects will likely participate in the power markets by bidding both quantity and price.

Renewable energy market participation should take many forms. For new projects, participation in the power market can be diversified by referring to international experience and domestic demand, including power purchase agreements signed with power consumers or purchasing and selling companies, medium- and long-term contracts, competitive bidding by the government or purchasing and selling companies, direct participation in the spot market, and combination of the previously mentioned models.

For existing projects that previously had feed-in tariffs set as benchmark tariffs, set via competitive bidding, or tariffs including a subsidy, as well as benefitting from the full purchase guarantee policy, China should encourage their participation in the power market. If China can shift to participatory markets, the issue of policy continuity must be addressed. For example, China might consider shifting from the feed-in tariff model to the market premium model or the differential price contract model. Shifting to a new model would depend on preconditions. The spot market should be a mature market that realizes fully competitive pricing. Prior to establishing mature spot markets, renewable pricing should link the level of premium or price difference with the price in the power market.

There is no need for renewable energy to participate in irrational competition in the imperfect power market. At present, power competition in a few regions or period of time is irrational, especially in regions and hours with sufficient power supply. Coal power is only quoted at variable cost or variable cost plus part of fixed cost, resulting in low price. Some regions have adopted the direct transaction or direct purchase model between power generation enterprises and power consumption enterprises. The price is brokered by the government, resulting in a price lower than the actual cost of coal power.

The cost of onshore wind and PV is economically competitive compared with that of coal power today, which has led to the withdrawal of their feed-in tariffs. If the market is in the stage of irrational competition, it is unhelpful for wind and PV to participate in irrational competition. In this case, it is recommended to continue the benchmark tariff parity pricing or auction-based pricing policies for wind and PV for a period of time. In 2019, China implemented a new auction system for PV generation. Our analysis shows that the major elements of this system, such as competitive allocation, national ranking, amended tariff, and forewarning management, are also applicable after the complete removal of subsidy for wind and PV. The feed-in tariff will be lower than the price of coal power through auction or bidding (in August 2019, the final bid prices for PV in projects auctioned were lower than the respective local coal benchmark prices). The power purchase agreement (PPA) or contract-for-difference (CfD) model should be implemented.

Renewable energy power planning and management mechanism

Planning and management policies must meet multiple objectives. During the 14th Five-Year Plan period, wind and PV will play a growing role in power systems in terms of capacity and output. After the tariff subsidies phase out, and as wind and solar become increasingly competitive with coal, policymakers may need to limit annual wind and PV additions to prevent new grid bottlenecks. Policymakers will also need to avoid the risk of large swings in the renewable market and industry that unlimited growth might produce. On the other hand, policies will need to prevent grid and market constraints on renewable development, ensuring bottlenecks do not lead to a sudden collapse of the renewable industry. In other words, policy must support China's transition to clean energy, ensure the sound development of manufacturing industry, while also ensuring integration of electricity demand and absorption of renewable output.

Stable development of renewables including wind and solar requires improved grid integration and uptake of RE. To enable healthy wind and solar development, policies should ensure that grid companies and third-party organizations annually publish five-year electricity demand forecasts, including forecasts for absorption of new wind and solar output, establish a mechanism for regularly publishing forecast results, and use this as the basis for wind and PV development and policies. The market should guide the timing and location of new wind and solar projects via competitive allocation of construction quotas. When China's wholesale power markets mature, wind and PV additions will more depend on market forces.

Consumption guarantees for renewable energy remain essential over the long-term. China issued its most recent policies guaranteeing the consumption of renewable energy power in May 2019. The policy establishes mandatory consumption targets and responsibilities, along with indicators in order to guide the consumption of renewable energy power. The policy includes aspects that promote both supply and demand of renewables, both in the near-term and long-term. After wind and PV prices fall below present grid tariffs for coal and subsidies are withdrawn, renewable uptake will be the most important factor affecting annual installations of wind and solar. To meet China's need to continue wind and solar installations and thereby achieve long-term national clean energy targets, renewable demand responsibility should at least remain stable or grow over time, to create space for sustainable growth of renewable energy.

Economic policies for renewable energy

Removal of subsidies does not imply removal of economic policies—reducing or eliminating non-technical costs remains critical. International experience indicates that economic policies related to non-technical costs—soft costs such as regulatory expenses, marketing costs, land use fees, and financing costs—become more important as renewable energy reaches cost-competitive levels and participates in power markets. For example, in 2016, a PV generation project in the United Arab Emirates (UAE) bid a price of US$ 0.0242 cents/kWh in a power auction, and this price was only possible due to the country's land tax exemption policy, consumption tax exemption policy, long-term low-interest loans, and summer tariff policies. The 12 measures proposed by the National Energy Administration in 2018 to reduce the regulatory cost burden on renewable energy companies should be sustained and strengthened in the post-subsidy era to reduce non-technical costs, especially unreasonable non-technical costs. On land policy, some regions still violate national regulations or collect unreasonable renewable energy resource fees and urban land use taxes. The basic principles of land availability and land cost for renewable energy development should be clarified and national policies should be fully implemented.

Supportive policies are still needed for some renewable energy sources. For not-yet fully commercial renewable technologies, economic support remains necessary for scale-up. Examples of these technologies include biomass and solar thermal energy. For biomass power from agricultural and forestry residues, raw materials account for at least two-thirds of the generation cost. Prohibition of straw burning via education, agricultural transfer payments, and subsidies for procurement of biomass would support development of biomass power. For large-scale solar thermal plants, such as utility-scale concentrating solar, these remain in the initial stage of industrial development, but the energy storage and flexibility aspects of the technology suggest they will have value in the world's future renewable-based energy system. For CSP technologies, competitively set tariffs for new projects combined with annual installation targets would ensure continued development. Grid companies should sign the PPA and the high cost should be covered by the end-users reflected in the retail price of power. Alternatively, the differential price should be provided through the renewable energy development fund. If such technologies participate in power markets, they could do so under a contract-for-difference arrangement.

11.2 Renewable heating

Overall renewable heating policy

High-level policies can stimulate the market for renewable heating. The renewable heating experience of other countries shows the importance of supportive national policies. These policies include overall national targets for renewable energy and reduction of greenhouse gas emissions, energy taxes and carbon taxes, and full accounting for social and environmental external costs. Such policies not only establish a favourable market environment for renewable heating, but also reduce and thereby clarify the need for specific supporting policies for individual renewable heating technologies.

At present, without considering external cost factors such as the environment, China's renewable heating remains uncompetitive with traditional fossil heating such as coal. Therefore, from the perspective of policy framework, China should gradually improve the macro policy environment. For example, China should strengthen efforts to control total energy consumption, increase incentives to reduce greenhouse gas emissions, study and improve energy and environment taxes to internalize the external costs of fossil energy, incorporate renewable energy into the energy saving requirements of buildings, and explicitly request that the proportion of renewable heating in new buildings and communities should meet emissions standards. Although some of these policies are beyond the scope of renewable heating incentive policies, they remain important for promoting the development of renewable heating.

China will prioritize renewable heating development and planning. Given the importance of public awareness to this topic, China will continue to improve public education of the role of renewable heating in controlling air pollution and emphasize the importance of renewable energy in solving clean heating in China. The interconnection of different heat sources in China's winter heating zones should be strengthened to realize the optimal scheduling of the heating system. China should prioritize renewable heating over other heating sources for urban heating pipe networks as well as for heating utilization.

Renewable heating should be included in local infrastructure plans, and policymakers at various levels should coordinate the utilization of renewable heating. Regional energy transformation demonstration projects should include renewable heating targets, incorporate renewable heating into unified regional planning, and include renewable heating as an indicator in the regional ecological civilization construction evaluation system.

Various renewable heating technologies, such as solar energy, biomass and geothermal energy, should be included in the preferred technology catalogue for air pollution, energy conservation and emission reduction. China should clearly put forward the overall development goal of renewable heating of the country and the development goals of key provinces. In the planning and construction process of new urban district construction, reconstruction of old city and construction of industrial parks (areas), China should combine the regional energy planning with urban development planning and prioritize the simultaneous development of renewable power and heating. This should be the focus of the planning, design and transformation of urban heating systems and heat-supply pipe networks, optimizing the design of heat-supply pipe networks according to the characteristics of renewable energy.

Economic policy on renewable heating

Promote the market competitiveness of renewable heating. China should lift restrictions on access to heating and encourage private enterprises to enter the clean heating sector. China should promote the selection of heat suppliers by competitive bidding and other market-oriented ways. Heat supply enterprises that manage heat sources, pipe networks, and heating fees in an integrated way should be allowed to determine heating areas and corresponding heating subsidies through franchise and other business models. In case that a heat supply enterprise sells heat to a heating company through a contractual heating transaction, a long-term heat supply agreement may be signed with the heating company with the coordination of the government. For users who cannot be covered by central heating, China should promote the development of decentralized renewable heating through the combination of user investment and government subsidies.

Establish and improve the heating price policy. The pricing and compensation mechanisms of renewable heating should be explored. China should determine the national guiding prices of various heating technologies according to the application level and condition of such technologies, especially for solar energy heating, biomass cogeneration heating, biomass boiler heating, and middle-deep terrestrial heat. The environmental externalities should be considered in the determination of heating price.

The construction and reconstruction cost of heat-supply pipe network of renewable heating projects should be included in the urban infrastructure costs, which shall charge according to the different standard of the construction of conventional heat-supply pipe network. China may adopt different prices for different heating users. For instance, prices for commercial heat and industrial heat should adopt market means and be determined through negotiations between enterprises. Prices for space heating and hot water should be determined through hearings, and the charging model based on heat quantity should be implemented to encourage heating stations to operate according to the new mode of energy saving service.

Support technology development and demonstration. China will support research and design optimization of new systems, including a multi-energy complementary system for renewable energy—which involves the integration of renewable energy and conventional energy systems, and can include combining renewable heating with other energy sources and storage. China will increase fiscal, tax and financial support for demonstrations in these fields. Renewable heating should enjoy tax incentives and energy-saving subsidy policies, as well as preferential green finance and green bonds policies set by the national government. Policies and supports should particularly favour projects that affect household heating, involve major renovation work, demonstrate significant innovation, and strictly abide by environmental protection standards.

A new supervisory system for renewable heating

Improve the standard system for renewable heating. China should study and formulate standards for measuring and accounting for renewable heating, which will require carrying out heating measurement of individual renewable heating projects as well as establishing monitoring and statistics systems related for renewable heating. China should strengthen the testing and certification system for the renewable heating products, establish third-party testing and certification institutions, as well as develop and improve the quality certification system for renewable heating equipment and engineering services. Combined with the reformation of the power system and the construction of the power market, China should establish an information platform to coordinate energy flow and other data from the electric power grid and the heat networks.

Strengthen environmental supervision of renewable heating projects. For projects that may affect surface water, underground water, soil, or air quality, China should improve the overall supervision system before, during, and after the renewable heating project's initiation. This entails monitoring geothermal energy development and utilization, including real-time monitoring and dynamic evaluation of the exploration, development, utilization and environment condition of geothermal energy resources. Regulators should fully implement requirements for reinjection of geothermal tail water and ensure the balance of extraction and injection. China should develop technical standards for biomass heating as an alternative to coal heating, and improve technologies for low-nitrogen combustion of large biomass boilers and equipment manufacturing. China should promote the manufacturing of standardized, serialized and complete set of equipment, and formulate standards for biomass heating engineering design, briquette-fuel products, molding equipment, biomass boilers and emissions. In areas where mandatory installation policies such as solar heating are implemented, supervision and management of project construction and operation should be strengthened.

11.3 Renewable energy gas

The gas produced from renewable energy sources has many benefits, such as supplanting the use of gas from fossil fuels while reducing emissions of methane. The current trend is toward greater utilization of marsh gas production by fermentation of livestock manure, straw and other raw materials, and biogas production by purification. Development of this industry requires coordinated management across departments and fields, especially the sorting and integration of upstream raw materials and promotion of consumption of renewable energy gas.

Establish a collaborative management system for the biogas industry. China should clarify the responsibilities of the leading authorities and departments for the biogas industry. The field involves multiple departments of finance, development and reform commissions, agriculture, environmental protection, energy, housing and construction, taxation and quality inspection. These departments should jointly study and formulate industrial goals, plans, policies, and standards, and work together to promote the industry.

Strengthen industrial supervision and management. After the completion of biogas projects, professional third-party evaluation agencies should assess each project according to project feasibility report, implementation plan and operational impact of the project. China should study and formulate a project grading evaluation mechanism, including grading completed projects on environmental impact, technical advancement, sustainable operating capacity, and innovation. The grading should be linked with subsidy and tax policies to ensure the construction quality and actual production impact of the projects. The blacklist or credit system should also apply to such projects, in order to notify and penalize companies with records of multiple ineffective projects.

Encourage social capital to participate in the construction of the collection, storage and transportation of agricultural organic wastes. To encourage innovation in the implementation of biomass-related policies, China should define new ways to integrate social capital investment with government investment in waste regulation, prohibitions on straw burning, fees for sewage and waste disposal, and environment taxes for livestock and poultry farms. To encourage social capital to participate in the collection, storage and transportation of agricultural organic wastes, policymakers can establish investment subsidies, co-equity investments, long-term off-take contracts, and PPPs. China should improve preferential tax policy as well as include agricultural organic waste collection and treatment services in the scope of VAT refund and marginal relief. The government should particularly support biogas enterprises with high technical qualifications, strong financial strength and good records of project implementation to participate in the collection of crop straw and manure disposal of livestock and poultry breeding, and allow these enterprises enjoy preferential VAT and income tax discounts and/or exemptions.

China should study and formulate the biogas blanket guarantee purchasing policy, in accordance with the Renewable Energy Law. China should promote the blanket purchasing or quota guarantee purchasing of biogas by pipe network enterprises, improve the supportive policy for the construction of centralized gas supply pipe network in rural areas, and ensure that biogas and marsh gas power generation and central gas supply are treated equally in the market. The law requires that gas pipe network operators and gas sales must purchase the locally produced biogas products at reasonable prices. In addition, China may explore ways to ensure full consumption of biogas products, such as granting franchise rights to biogas stations.

Study a gas quota system for renewable biogas. Given the successful roll-out of China's green certificates system for renewable electricity, the ongoing national reforms of the oil and gas sector and gas pipeline sector, China should research a gas green certificate system. In such a system, gas pipe network companies and gas sales companies would be required to guarantee a certain proportion of biogas shares and take a certain volume of biogas products. China should promote the green gas quota system and remove the restriction of gas franchise on the market consumption of biogas products.

11.4 Biology liquid fuel

Biofuel ethanol

Biofuel ethanol production should match reasonable rates of consumption. The Implementation Plan on Expanding the Production of Biofuel Ethanol and Promotion of Ethanol Gasoline for Vehicles (FGNY [2017] No. 1508) and the Overall Layout Plan of the National Biofuel Ethanol Industry (FGNY [2018] No. 1271) state that China should promote biofuel ethanol nationwide by 2020. In 2018, China consumed about 3.15 million tons of biofuel ethanol, far from the market demand of 13 million tons. Thus, nationwide uptake of biofuel ethanol will likely shift to the 14th Five-Year Plan period. To ensure a stable supply of biofuel ethanol raw materials, policy-makers should set production and consumption policies to avoid situations where biofuel ethanol producers cannot meet demand.

Increasing research and development of biofuel ethanol from non-grain raw materials. Due to limits on raw material availability, China should supplement domestic production of biofuel ethanol needs with non-grain biofuels. Non-grain biofuel ethanol has not achieved large-scale development yet, and raw material cultivation guarantee and production technology would require technological breakthroughs. China should focus on the research and development of biofuel ethanol from non-grain raw materials, to solve the urgent task of realizing nationwide use of biofuel ethanol.

Biodiesel

Strengthen raw material management, and regulate the upstream industry system. The raw materials of biodiesel in China mainly come from animal and vegetable fat and oil waste and waste cooking oil. Such organic wastes must be treated and disposed of, and there is a major food safety risk caused by the return of gutter oil to the table. It is urgent for China to standardize the collection, transhipment, disposal and supervision of the upstream raw materials of biodiesel such as gutter oil. China should establish a long-term management mechanism and enforce the regulation of the industry management system through local legislation. This will ensure safe flow of raw materials, such as gutter oil, and provide a raw material guarantee for biodiesel production.

Carry out pilot projects for biodiesel mixing. In China, the application and promotion of biodiesel in the field of transportation is very narrow and limited to the production of plasticizer and other chemical products. The pilot application and promotion of biodiesel should be carried out according to the promotion experience of biofuel ethanol, to provide a broad market for biodiesel and form a sustainable circular economic industry chain.

11.5 Conclusions

The scenarios and paths of energy development (which is characterized by high proportion of renewable energy) are proposed and analysed in detail in the third part of this report. Realizing this vision requires the development of technology and industry as well as effective policies.

The 14th-five-year will be milestone for China renewable energy development, as the innovative key policy mechanisms will impact the renewable energy development in the short and long-term.

12. Recommendations for Innovation and R&D

12.1 Build up a strategic system for energy technological R&D and innovation

Formulate national innovative development strategy for energy sector and support technological breakthrough in key fields. The government will focus on key technologies that currently hinder the development and may lead to revolutionary breakthroughs. It will lead to formulate the strategies, plans and policies that can support innovative technological development, as well as breakthrough the bottleneck of core technologies. China expects to establish a coordination mechanism in field of energy technology that integrates the resources of governments, industries, universities and research institutes, based on an innovative management system. Meanwhile, the government will improve the supporting policies and regulations covering energy transition based on technological legislation, technology commercialization, intellectual property protection and standard making. To establish an innovative R&D culture is another goal, which implies the development of a diversified, innovative, permissive and competitive environment. China also aims to improve the quality of equipment standards, to establish and improve the processes on quality testing, certification and inspection. It will build up an evaluation and incentive mechanism for technical experts, based on the individual capacity and contribution.

Persist on market orientation and stimulate the motivation and innovation of enterprises. The government targets to establish an enterprise-led innovative technological mechanism to felicitate energy transition, specifically on energy innovation, R&D investment and product commercialization, for which the formulation of a healthy market environment can play a key role. China will particularly guide enterprises to increase investments in innovative energy technologies, especially capacity building in large scale state-owned companies and private companies. The weighting of technological innovation in evaluation criteria of state-owned energy enterprises could be increased. For small scale enterprises, the government will promote private companies to carry out technological innovation tasks assigned by the relevant authorities. China could deepen the integration of production, study and R&D sections, creating a channel to bind industrial, technological and economic development. Moreover, the country expects to increase success rate of product commercialization and encourages innovative technical alliances in industries that are enterprise-led and production-study integrated.

Increase investment and support in technology innovation and optimize management mechanism for high-tech projects. The share of high-tech investments can be increased by raising up the relevant proportion in central government's annual budget and in government managed funds. The industry should focus on breakthrough of major technological projects around generic of technologies, equipment and standards for energy transition. In the meantime, the government will provide guidance for venture investment and private equity investment to implement innovative fiscal and tax policies and facilitate localization of major technological equipment. Besides, the management standard for high-tech projects should be improved in parallel, simplifying the approval process of the *State Programs of Science and Technology Development*, as well as reducing government intervention and improving transparency. The government shall implement incentive mechanisms for participants, in a way that the life-long expert system for the *Program* will be cancelled. In addition, the industry should avoid blindly following suit on determination of technological innovation direction.

Support sector coupling to inspire the potential and advantages of collaborative innovations. The industry should bind hardware and software more tightly. Integration of energy with physics, chemistry, material and meteorology science, as well as sector coupling of power, heat and gas networks, is necessary.

Continue to support the innovations that are self-dependent or through international cooperation. The industry should aim at global cutting-edge technologies. Self-dependent innovation of technology should always be the core solution in energy transition process; parallelly, China should be more open to carry out international collaborations with a broader scope. The industry should take advantage of new technologies, methods and concepts around the world, to form a united and coordinated innovation system.

12.2 Key areas of technological innovation

Large-scale renewable and hydrogen utilization technology

Innovation in efficient utilization of solar energy

The industry should further research on key technologies that are beneficial for the industrialization of efficient and cost-effective crystalline silicon cells and develop key materials to support them. The main focus includes the production lines of crystalline silicon cells with average efficiency exceeding 25% such as HIT cell, TopCON cell technology and IBC cell. Furthermore, the government can encourage implementing demonstrations for high-efficiency battery pack production and application.

It is necessary to develop new types of photoelectric converters with higher efficiency and lower cost, as well as breakthrough the technological bottleneck in industrialization processes. By doing so, China would master the technology, production process and equipment for industrialization of thin-film battery such as CdTe, CuInGaSe and Si Film.

The industry should greatly improve cell efficiency and achieve localization of key raw materials. The targeted technologies include building integrated PV, smart PV plants, wind-PV-CSP hybrid power plants, DC grid connection of distributed PV and PV micro-grid. China aims to develop a demonstration project of 50 MW wind-PV-CSP power system with heat storage equipment assembled.

Innovation of large-scale wind power technology

In order to expand the application of wind power generation at height of 200 to 300 meters, China would need to deepen the research on the full package of technologies for large scale wind power system at such height, key technologies for large scale high-altitude wind turbines, and design and manufacture of 100 meters and above wind blades. The industry should study in depth the offshore wind resource characteristics and its utilization methods. The main goal is to develop local offshore wind resource assessment system, understand the complexity of wind conditions and make optimal decisions regarding site selection. The government should require to breakthrough key technologies on design and construction of high sea offshore wind power plants, including the infrastructures to support wind turbines, site selection, deployment, building, construction, operation and maintenance of the project.

China should implement R&D on 10 MW and above offshore wind turbine with independent intellectual property rights, and key components such as bearing system, control system, converter and blades. Operation, control and grid connection of offshore wind power bases based on big data and cloud computing technologies are also a key task. Additionally, China will focus on mastering key technologies such as cluster control of large-scale offshore wind power bases based on big data, optimal control and intelligent maintenance of offshore wind power bases, real-time monitoring and smart diagnosis system for offshore wind farms.

Research on key technology of large-scale hydropower

The government aims to make breakthroughs in hydropower engineering under complex construction conditions, such as high earthquake-intensity areas and ultra-deep overburden layers. It involves engineering technologies for large-scale underground caverns, high-pressure watercourse lining structure and high-pressure grouting, temperature control and crack prevention of high-duty mass concrete, dam foundation treatment in high earthquake-intensity areas and ultra-deep overburden layers, as well as construction technologies under ultra-high ground stress conditions.

The industry should master the key technologies for the safety, emergency, terrorism and riot prevention for cascade hydropower stations. The key technologies for multi-objective coordinated optimal operation of cascade hydropower stations based on hydrological forecast is also an important focus, as well as the technologies for optimal siting, retrofit and retirement of cascade hydropower stations. The country would build a basin environmental monitoring system and database platform, dynamically monitoring the evolution rule of the ecological environment of the basin hydropower development.

Innovation in utilization technology of biomass, marine and geothermal energy

The government aims to make breakthrough in advanced biomass energy and chemical technology. The industry should carry out large-scale industrial demonstrations of biological aviation oil (including military), cellulosic ethanol and green bio-refinery. In the meantime, it should study new varieties and high-efficiency energy plants, build ecological energy farms, and form an advanced bio-energy chemical industry chain and a sustainable supply system of biomass materials.

China should also strengthen the development and utilization of marine energy, develop efficient wave energy, tidal energy and thermal (salinity) gradient energy generators. The industry expects to build megawatt demonstration power stations and form a complete industry chain of marine energy utilization.

The development and utilization of geothermal energy is also necessary. Specifically, China should focus on the retrofit and productivity increment technologies for hydrothermal geothermal system, as well as investigate key technical equipment for the development of dry hot rock and build megawatt demonstration projects for dry hot rock power generation and cascade utilization of geothermal energy.

Innovation in hydrogen energy and fuel cell technology

The industry should study the large-scale cost-effective hydrogen production technology based on renewable energy. Distributed electrolytic hydrogen production technology that can adapt to the rapid variable renewable energy is an important technology to develop, and establish a standardized on-site hydrogen production mode for hydrogen refuelling stations and demonstrate its application is a target.

Another goal consists of the development of the key materials and technical equipment for hydrogen storage and transportation. Such achievement will allow large scale cost-effective integration of hydrogen production, storage, transportation and application, achieve standardization and promotion of various hydrogen on-site production and storage modes for hydrogen refuelling stations.

Meanwhile, in order to realize demonstrative operation and market expansion of PEMFC automobiles, the industry should formulate technical solutions to manufacture the key materials and components and realize system integration for high-performance PEMFC. The industry should also focus on distribution power generation technology based on PEMFC and SOFC, realizing the demonstration application of high-power distributed power generation system, and explore the marketing mode.

Key technologies for the new generation of smart energy system adapted to a high proportion of renewable energy

Innovation in key technologies for modern power grid

China will study intelligent control technologies for modern power grids. The goal is to master key technologies for large-scale renewable energy and distributed grid-connected operation and carry out demonstration projects. The government also expects breakthroughs in the overall coordinated control technology for the power system and demonstration of new applications.

China aims to master advanced power transmission and transformation equipment technologies such as flexible DC power transmission and distribution technology, new high-capacity high-voltage electric and electronic components technology and high-voltage submarine power cable. The country will also focus on the research, experiment and demonstration of DC power grid technology as well as future technology for power transmission. China will support studies on key technologies and processes for energy equipment components, such as high-temperature superconducting materials, new insulating medium and sensing materials and devices for power equipment. It is also necessary to research the security and stability technology for modern complex large power grid, in order to achieve a safe and stable operation of modern complex large power grid.

The country will also focus on simulation technology for modern complex large power grid leveraging big data. Such an approach will make full use of the mutual coordination technology between micro grid/LAN and large power grid, as well as the intelligent control technology for source-network-load coordination.

Innovation in advanced energy storage technology

China will support research on chemical energy storage technologies for grid-connected of renewable energy, distributed and micro-grid and EV applications. The emphasis is high-safety, low-cost and long-life battery technologies, including lithium-ion batteries, lead-carbon batteries, sodium-sulphur batteries and vanadium redox batteries.

The country also aims to study physical energy storage technologies for peak load regulation and efficiency improvement of power grid and regional energy supply. It targets at developing its own independent intellectual property of the new compressed air energy storage technology, flywheel energy storage technology and high-temperature superconducting energy storage technology.

China will also conduct research on the high-temperature heat accumulation technology for the efficient utilization of solar thermal and the high-capacity heat (cold) accumulation technology for distributed energy system. The target is to master the key core technologies for various links of energy storage technologies and verify the demonstration projects.

Innovation in energy Internet technology

The government will support research on key energy conversion technologies, such as high-temperature superconducting materials, high power electronic devices, integrated power generation/energy storage fuel cells, and heat pumps for regional thermal energy taste regulation. This research will support the development of standardized energy routers. Using power grid and pipe network as backbone network, China will coordinate the interconnection of cold, hot, water and gas networks, and build a multi-energy collaborative energy network.

The country will also enhance innovation in energy internet integrated technology. It will focus on technologies such as the efficient integration and intelligent control of information systems and physical systems, the integration and safe sharing of energy big data, the application and management of energy storage and EVs, and the demand-side response. It also aims to form a relatively complete technical standard system.

Innovation in advanced nuclear technology

China intends to realize the demonstration application of self-developed advanced nuclear fuel element. It will promote the irradiation test and commercial operation of ATF and annular fuel element. The country intends to possess the international leading R&D capability of nuclear fuel element.

As China's third generation PWR technology has been at a leading level in the world, the country will focus on promoting the construction of fast reactor and advanced modular small reactor demonstration projects, as well as the construction of an advanced nuclear fuel circulatory system. The objective is to make major breakthroughs in basic theory and R&D of key technical equipment and materials for the new generation of advanced reactors, such as ultra-high temperature gas cooled reactors and molten salt reactors.

Technologies for energy conservation and efficiency improvement

The industry should strengthen innovation in energy-saving technologies. It should focus on conducting researches and carrying out demonstration projects on efficient industrial boilers (kilns), innovative energy-saving motors, deep recycling of industrial complementary energy, and energy conservation of industrial systems, based on advanced information technology.

The construction industry should innovate in energy-saving technologies, such as building industrialization, prefabricated housing, and energy efficient smart devices. In the transportation industry, China will promote innovation in advanced transportation energy-saving technologies such as energy-efficient vehicles, braking energy feedback system, and transportation system based on advanced information technology.

China will also enhance innovation in energy-saving technologies for global optimization systems such as the cascade utilization of energy. It will make research and demonstration on comprehensive energy utilization technologies, such as the replacement of bulk coal, to support the country in achieving the goal of energy conservation and emission reduction.

Technologies of the green mining and clean low & zero carbon utilization for fossil energy

China expects technology innovation in extracting unconventional oil & gas, deep oil & gas and deep-sea oil & gas. It will develop extraction technologies, aiming at the efficient extraction of unconventional oil & gas such as shale oil & gas and coalbed methane. The government also expects to master the technologies for deep-sea oil & gas exploration and extraction. It will comprehensively improve the technological level of deep-sea oil & gas drilling and the capability of independent equipment constructing. The target is to realize the independent and efficient extraction of oil & gas fields at 3,000m and 4,000m ultra-deep water.

China also aims at making breakthroughs in the basic theory and key technology for NGH exploration and extraction, as well as carrying out pilot drilling and trial production tests.

Revolutionary technologies associated with energy development

China expects breakthroughs in the high-temperature superconducting technology and its application in power transmission, energy conversion and storage. The industry should explore controllable thermonuclear fusion technology. It should carry out experiments on fusion reactor core combustion plasma and conduct research on its control technology. It should also focus on the design of fusion demonstration reactor DEMO. The government will encourage the integration of AI, big data, 5G and other key technologies with energy production and consumption.

12.3 Innovation in business models

Innovative business models play a vital role in promoting energy transformation and accelerating new technology introduction. With the increase of distributed energy, China will gradually introduce more flexible and innovative business models into the energy field through resource sharing and diversified development of market traders.

Integrated energy service model

The integrated energy service model aims to sell services to customers instead of selling electricity. By purchasing energy services, customers can reduce the energy consumption cost and improve their comprehensive energy utilization efficiency. Energy service providers, relying on the energy efficiency data sharing platform, are able to fully exert their advantages on energy data resources and provide customers with energy efficiency improvement services. They can promote integrated energy services such as market-oriented electricity sales and integrated energy consumption of electricity, water, gas and heat. They can also expand service models such as electric energy substitution, energy-saving, multi-energy complement and energy consumption monitoring and diagnosis in areas.

Australia, China, Finland, Ireland, Italy, Japan, Sweden, the United Kingdom and the United States have adopted the integrated energy service model. In China, both State Grid and China Southern Power Grid have taken integrated energy services as their next business expansion direction and started to establish corresponding institutions. For example, State Grid has built the Tongli Integrated Energy Service Centre and has put it into operation.

"Energy aggregator" model

Energy aggregator (also known as "virtual power plants") can aggregate many distributed renewable energy sources at the same time, producing a comparable capacity to conventional power plants. Energy aggregators can sell electricity directly to the wholesale market and provide ancillary services to grid operators, for a smooth integration of distributed energy sources into the power system. Therefore, energy aggregators contribute to power system flexibility. Energy aggregation companies have already been established in Australia, Belgium, France, Germany, the Netherlands, the United Kingdom and the United States. In the United Kingdom, there are 19 energy aggregation companies, with about 10 GW of installed capacity. In order to develop the "energy aggregator" model, China expects to make breakthroughs in power market and supporting mechanism.

P2P trading model

P2P trading mode creates an online marketplace platform for energy trading, where consumers trade peer-to-peer with distributed energy suppliers. The main goal of P2P market is to provide a transparent and credible platform for producers and consumers. The platform equitably balances the preferences and needs of both power producers and consumers, to achieve a win-win situation for all the participants. An important mode for P2P trading consists of building the trading system based on blockchain technology in micro-grid application scenario. It encourages the development of distributed renewable energy generators and the consumption of local energy. Germany, the Netherlands, the United Kingdom and the United States have carried out some demo projects using P2P models . In China, some energy blockchain labs are actively exploring the P2P trading mode. However, at the operation level, similarly to power transactions with nearby power users within a distribution network, it requires the establishment of corresponding rules on the T&D cost mechanism.

Community ownership model

Community ownership (CO) model aims to manage energy-related assets uniformly in communities and allow community members to share the benefits of renewable power plants. The CO model can supply renewable energy to consumers who are unable or unwilling to install power generation facilities on their buildings. The model encourages the energy generation and consumption from local renewable energy sources. Currently, there are more than 4,000 renewable energy communities around the world, mainly in countries such as the United States, Europe, Australia, with project scale ranging from 50 kW to 10 MW. In China, this model is technically available. However, there are still ambiguity in implementation, such as the asset management of renewable energy projects, ownership of the community building roofs, and the role of power grid enterprises.

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