国家发展和改革委员会
能源研究所
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国家可再生能源中心
CHINA NATIONAL RENEWABLE ENERGY CENTRE

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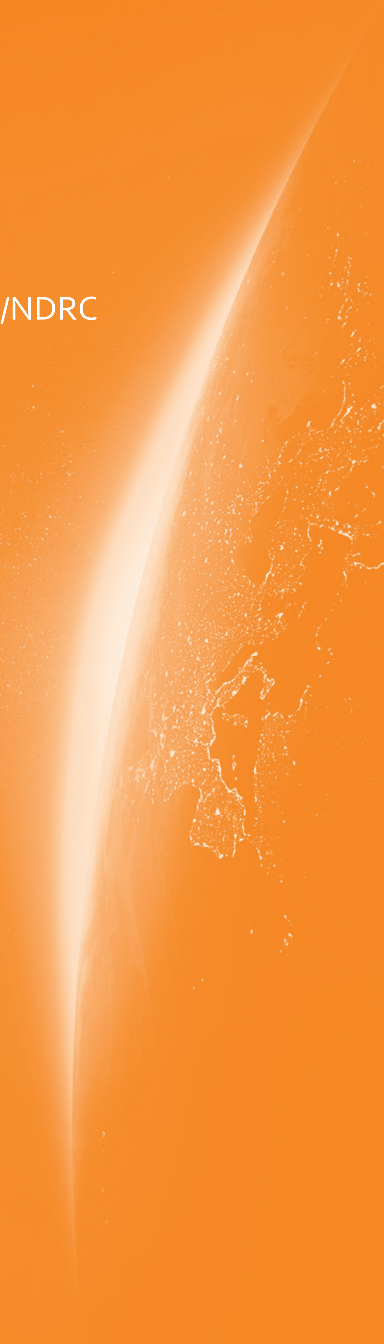
China Renewable Energy Outlook

2018

Energy Research Institute of Academy of Macroeconomic Research/NDRC

China National Renewable Energy Centre



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Domestic Supporting Institutes

College of Environmental Sciences and Engineering, Peking University
State Grid Hebei Economic Research Institute
North China Electric Power University

29 November, 2018

"We will promote a revolution in energy production and consumption, and build an energy sector that is clean, low-carbon, safe, and efficient."

"What we are doing today to build an ecological civilization will benefit generations to come. We should have a strong commitment to socialist ecological civilization and work to develop a new model of modernization with humans developing in harmony with nature. We must do our generation's share to protect the environment."

President Xi Jinping

at the 19th National Congress of the Communist Party of China

October 18, 2017

Foreword

China is in the beginning of an energy transition with the aim to build an energy system for the future. The 19th Party Congress in October 2017 confirmed and reinforced the direction and ambitions to complete the development of a moderately prosperous society by 2020; to achieve basic modernisation by 2035 and build a great and modern country which is prosperous, strong, democratic advanced, harmonious and beautiful by 2050. Strong emphasis is placed on the transition of the development of the economy from High Speed to High Quality, a paradigm shift which shall also be adhered to in the energy sector. With the important milestones for 2020, 2035 and 2050, it is the policy of China to develop a "clean, low carbon, safe and efficient energy system".

This year's China Renewable Energy Outlook (CREO 2018) uses these ambitions as a starting point for defining a clear vision for the energy system in 2050. A vision which can not only support a continuation of economic development but also complies with the ambitious energy and environmental objectives for a sustainable ecological civilisation. A roadmap for implementing this vision is analysed and compared with the development pathway from the current policies influencing the energy system development. Finally, the report analyses the short-term policy measures to promote renewable energy as part the energy transition.

It is my firm belief that working with visions for the future is a necessary step in the energy transition process. Without strong visions for the energy system, the transition process will be too incremental and inevitable fail to achieve the long-term goal. On the other hand, the vision must be rooted in comprehensive quantitative analyses of the whole energy system to demonstrate how the visions can be realised and to link the energy system development with the enabling policy measures.

The energy transition is a complex process with many stakeholders and with many, often conflicting interests. It is my hope that CREO 2018 can contribute to a build a strong analytical platform and a foundation for the policy making and eventually for the successful energy transition in line with the overall goals from the 19th party congress.

Like the previous years, the CREO 2018 has been developed by ERI and CNREC in a strong cooperation with national and international partners. The research has been made possible by funding from the Children's Investment Fund Foundation and from the Danish and German governments. This strong and on-going support is invaluable for the quality and depth of the research and I am grateful that we can continue this unique cooperation between energy experts and donors.

Wang Zhongying

Acting Director General, Energy Research Institute of China Academy of Macroeconomic Research /China National Development and Reform Commission.

Director, China National Renewable Energy Centre

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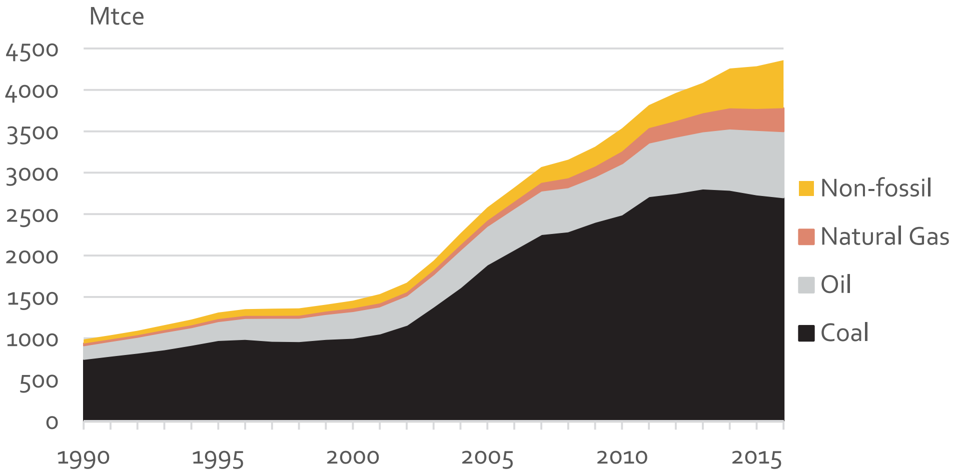
Introduction

Favourable conditions for coal built the current energy system

In three Five-Year plans - from 2000 to 2015 the 10th, 11th and the 12th - coal and oil have been strongly promoted as the main fuels for China's economic development. The coal power plants have been pampered with favourable dispatch rules, access to cheap capital, promoted by strong state-owned companies, and strongly supported by local governments. The industry has been allowed to surge coal consumption without the necessary consideration for the environment, and the transport sector has made the oil consumption rise to a level, where two-third of the consumption is imported.

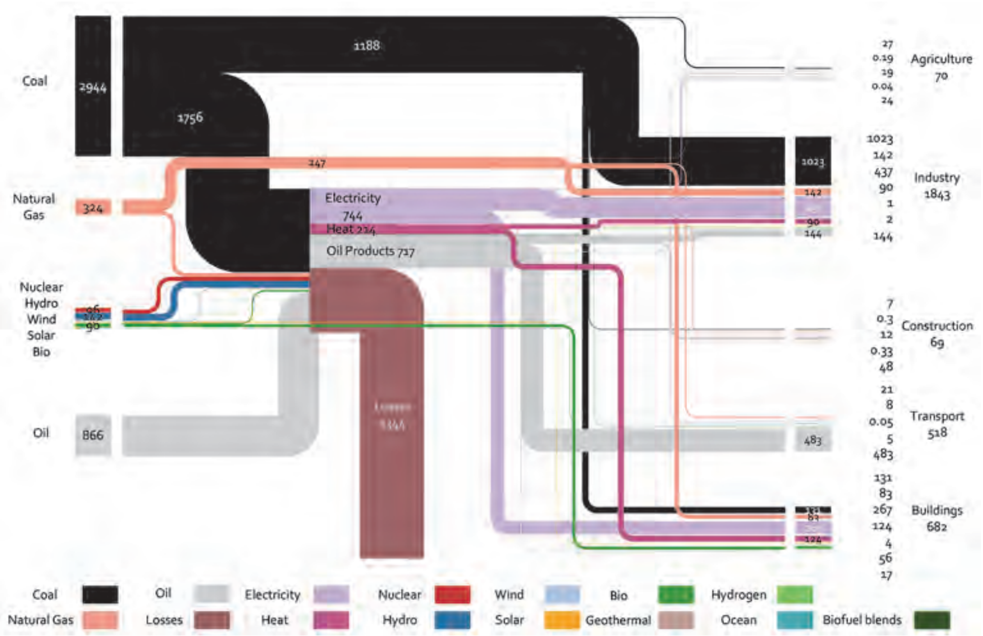
Figure 1: China's total primary energy demand (Mtce) 1990-2016



This build-up of the energy system has enabled rapid economic growth, but is also responsible for severe pollution of air, water and soil. The energy system is characterised by low energy efficiency, cost-efficiency has not been in focus in the energy sector, and China has become increasingly reliant on imported fuels.

Renewable energy has been promoted, but only as an add-on to the existing system. The result has been high curtailment of wind and solar power due to lack of integration into the power system and relative high subsidy levels to compensate for the additional risk factors for RE projects.

Figure 2: China's energy balance (Mtce) for 2017

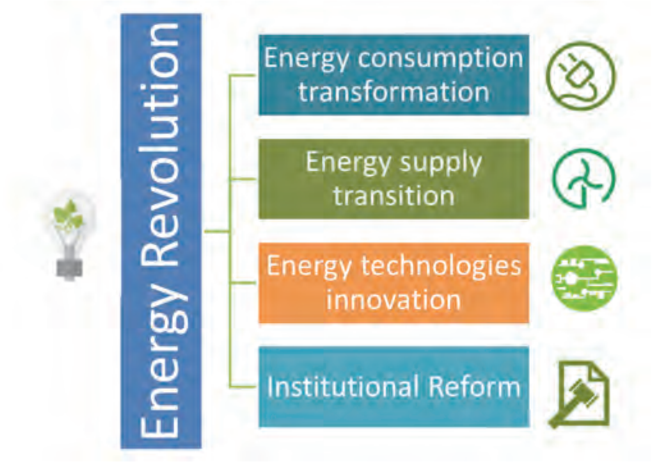


Shift in focus from coal to ecological civilisation

The 13th Five-Year plan changed this development trajectory. The plan introduces ambitious targets for the future energy system development, "to build a clean, low-carbon, safe and efficient energy system and safeguard the energy security". The favourable conditions for coal power plants have been lessened for new plants, planned and approved coal power projects were stopped or delayed, an effort to better integrate renewable energy was launched, and more focus has been put on development of electric cars as a long-term solution for the ever-increasing oil-dependency in the transport sector. A power sector reform was re-initiated, and an ETS system for CO_2 was launched as regional and national pilots. China launched an innovation plan, China 2025, with focus on quality instead of quantity and with new technologies, including renewable energy technologies and electric vehicles as strategic emerging industries, which should form the backbone of the Chinese economy in the future.

In 2017, The Chinese Government released its Energy Revolution Strategy, which includes four parts: energy consumption transformation to check unreasonable energy consumption and cap primary energy (coal in particular) growth; transition in energy supply with a focus on clean coal and renewable energies; energy technology revolution to stimulate innovation; energy system revolution with institutional arrangement.

Figure 3: The four pillars in the Energy Revolution Strategy



The 19th Party Congress marks the beginning of a new era

The 19th party congress marks a new era for China's development strategy. The long-term (2050) and medium-term (2035) visions have become clearer and the concept of the "ecological civilisation" has been confirmed as a main driver for the economic development, with focus on clean air, clean water and clean soil, with equal attention to social and environmental sustainability, and with the clear understanding that economic development without ecological development is not any longer possible.

Hence the task for us in the research for the outlook for renewable energy in China is to make the ambitions from the 19th Party Congress concrete, quantitative and measurable, to set-up a feasible pathway towards the 2050 energy system, and to explore how such a vision can be implemented through short- and medium-term policy measures.

The global context

"We call on the people of all countries to work together to build a community with a shared future for mankind, to build an open, inclusive, clean, and beautiful world that enjoys lasting peace, universal security, and common prosperity." - Xi Jinping's report at 19th CPC National Congress

The Chinese energy transition should not be seen in isolation but rather in a global context because development trends in individual countries and regions impact possibilities and actions in other countries and regions.

Globally, climate concerns have become a main driver for energy transition. The Paris agreement set a new agenda for the global efforts to mitigate human made climate change, but it is also clear, that the world is not on track for meeting the Paris agreement goals.

The EU and its member states move to exceed NDC commitments

The EU has set a long-term goal of reducing GHG emissions by 80-95% by 2050 compared to 1990 and set concrete targets for 2030 regarding emissions and share of renewables. EU has launched the "Clean Energy for all Europeans" package as part of the energy transition efforts. The package includes elements regarding energy targets, strengthening the harmonised energy markets and market regulation and measures on improving energy efficiency. Germany and Denmark are frontrunners in the energy transitions in Europe, and both countries have long term plans for the energy transition. In Germany, a special coal commission on growth, structural economic change and employment is working on a consensus among stakeholders on a deadline for the exit of coal and on a detailed plan for how to deal with the structural changes this will bring. In Denmark, a new energy agreement will eliminate coal consumption in the Danish power sector by 2030, replacing coal with wind and solar power along with biomass and biogas power generation.

The U.S. sustains progress on energy transition despite setbacks at federal level

The U.S. has seen several developments over the past two years that affect its energy transition. These include policy changes at the federal level eliminating policies related to climate change, state policies enhancing commitments to renewable energy, market reforms related to flexibility and distributed resources, and policy changes that could support energy storage paired with renewable energy. Independent of the federal government, several states and cities have formed the U.S. Climate Alliance to implement the U.S. NDC of economy-wide GHG reductions between 26-28% below 2005 levels by 2025 at the state level. A key policy instrument to achieve this goal has been the Renewable Portfolio Standard (RPS), versions of which have been enacted by 29 states. To date, RPS policies have contributed to 56% of the cumulative deployment of renewables in the U.S. since 2000. Since 2015, 10 states have raised or extended their RPS since 2015, and more states are likely to do so in coming years.

Mexico's rapid reorientation exemplifies feasibility of complex energy reform

Mexico is an example of how a developing country with a high dependence on fossil fuels can launch a rapid and comprehensive turn-around of the energy sector, both in terms of institutions and mechanisms. A power market reform is expected to be fully implemented during 2018. Three years since the initiation of reforms, technology-neutral auctions have been successful in driving down costs of new clean generation capacity and attracting qualified investors, and there is potential for Mexico to become even more ambitious regarding clean energy. Hence the country is likely to meet its clean energy goals more rapidly than announced.

China's development strategy is a platform for renewable energy leadership

Take-aways from the Global context examples for China should be clear. China's leadership in key aspects of renewable technology development, and forward thinking in terms of linking long-term development with visions for an ecological society, and ability to direct implementation of central policy towards massive implementation is an enviable platform for decarbonisation and a position of strength. Strengthening targets as in EU countries in effort to exceed that of NDC commitments, is critical and feasible and comes tremendous benefits as demonstrated in this report. Opposing forces may stall but not halt the energy transition as exemplified in the U.S. But it also highlights the need to seriously address the vested interest and ensuring support in areas negatively affected by energy transition, with different approaches and outcomes in Germany and the U.S. as an example. A cost-efficient transition can be achieved by joint efforts to push down the costs of new renewables and integration technologies, and by rapidly modernising energy and market regulatory frameworks and mechanisms taking inspiration from best practices in both developed and developing countries as exemplified by Mexico.

The 2050 energy system vision for China

The Chinese 2050 energy system is clean, low-carbon, safe and efficient

The Chinese energy system should in 2050 comply with all overall quality criteria, reflected in the 13th Five-Year plan and in the visions for an ecological civilisation as expressed in the 19th Party Congress:

- A *clean* energy system does not pollute the air, water or soil due to activities in the whole energy supply chain from mining to disposal of waste. This implies a drastic reduction of coal outside of the power sector, less coal-mining and efficient use of flue gas cleaning for the remaining coal-use in the power sector.
- A *low-carbon* energy system requires a general transition away from fossil fuels towards non-fossil fuels. Even though coal has the highest CO_2 content per unit of energy, oil and natural gas should also be restricted in a low-carbon energy system.
- A *safe* energy system is a reliable system, and a system with limited sensitivity to fuel import dependence. It follows that the use of oil and natural gas should be reduced since the inland resources are limited.
- An *efficient* energy system is efficient in the *use of energy*, meaning that useful energy is not wasted, the transformation losses are low and the energy efficiency in the end-use sectors is high. It also is a *cost-efficient energy system*, where the dispatch of the power system is based on least-cost optimisation, minimising the total cost for the whole system. Furthermore, planning and investment in new generation, and other energy infrastructure creates a cost-effective portfolio of assets working together to reduce overall costs. China has chosen to use the market forces as a decisive part of the economic transition and increasing the role of markets in the energy system specifically.

Combining these objectives, we get clear guidelines for the 2050 energy system of China:

- The dependency of fossil fuels, in particular coal, is reduced as much as possible, and substituted by non-fossil fuels in all sectors
- Energy efficiency is obtained by rigorous measures in the end-use sectors, by replacing thermal power plants with large conversion losses with renewable energy, particularly solar and wind which have low losses, and by electrifying the end-use consumption,

primarily the industry and transport sector. Efficient deployment of distributed energy sources further reduces overall system losses.

- The economic efficiency of the energy system is ensured through efficient power markets, and an incentive and taxation system, reflecting the direct and indirect costs of energy supply. This includes efficient costing of CO_2 emission and other pollutants.

CREO models and scenarios

CNRECs modelling platform

The analyses in CREO is based on a comprehensive modelling platform for the Chinese energy system. The platform consists of an end-use model using the LEAP software, a power and district heating model (EDO) based on the Balmorel model, and an economic model based on national input-output tables.

The end-use model represents the main economic sectors on a national level and uses relationships between drivers, energy intensities and fuel mix to estimate the future energy demand. The EDO model is a mixed integer/linear programming model, optimising the combined power and district heating system. The model represents the energy system on a provincial level, reflecting the constraints in the transmission system, and optimising the dispatch of the power generations and investments in the future power system.

CREO scenarios

CREO 2018 has two main scenarios: The *Stated Policies scenario* assumes full and vigorous implementation of the current and stated policies for the energy sector as expressed in the 13th Five-Year Plan and the 19th Party Congress. The *Below 2 °C scenario* goes further in the reduction of CO_2 emissions to support achievement of the Paris agreement goals. By comparing the two scenarios, it is possible to identify gaps between today's policies and the 2050 visions, and how they can be bridged by enhanced policies, targets, and measures.

Key assumptions

Below, the main scenario *boundaries* and scenario *assumptions* are introduced.

Scenario boundaries

The boundaries for the long-term energy and economic development are constraints to the deployment of various energy technologies:

- Renewable energy resources are constrained at provincial level, and wind and solar are divided into categories of costs, type and quality.
- Hydro power plants are limited to deployment of 532 GW, based on existing capacity and environmentally sustainable build out opportunities.
- Nuclear capacity is limited to 120 GW along coastal regions.
- CCS is not taken into account as a technology option, since no clear data on technology costs and performance is available.

Scenario assumptions

The scenarios are based on the following main assumptions:

- Both scenarios assumes full and vigorous implementation of the current and stated policies for the energy sector as expressed in the 13th Five-Year Plan and the 19th Party Congress. This includes a power market reform and an national CO_2 emission trading scheme.
- Economic development objectives must increase GDP by a factor of 4 in real terms, from RMB 82 trillion in 2017 to RMB 324 trillion by 2050.
- Both scenarios actively supports the new economic development by creating markets for strategic emerging industries like electric vehicles, data centres and IT services with high consumption of electricity and clean energy technologies.
- Population is expected to be on today's level at 1.38 billion in 2050.
- The short-term goals in the 13th Five-Year Plan on energy will be fulfilled in 2020, as well as the targets in the Three-Year Action Blue Sky Protection Plan, the 13th FYP for Environment Protection and the North China Clean heating plan.
- Energy efficiency vigorously reduces final energy consumption, e.g. in the Below 2 °C scenario is thereby 56% of a no improvement situation by 2050 and slightly higher in the Stated Policies scenario.
- Strong electrification of the final energy consumption, aiming at around 60% electricity in the end-use sectors.
- Focus on security of supply including strong efforts in reducing dependency of imported oil and natural gas.
- China achieves the goal of 10% of natural gas in total primary energy consumption by 2020 and in the Stated Policies scenario, natural gas consumption will increase to 15%. The Below 2 °C scenario does not require the share to increase after 2020.
- The 50% non-fossil electricity generation target of the Energy Consumption Revolution strategy is attained, and in practice exceeded in the scenarios.

- The Stated Policies scenario has the carbon intensity reduction target of 40-45% by 2020 and 60-65% by 2030, though this is not binding. CO_2 prices in the in the power sector rise linearly from RMB 50/tonne in 2020 to RMB 100/tonne in 2040.
- The Below 2°C scenario, the accumulated energy sector emissions from 2017-2050 is kept below 230 billion tons. This is based on several different simulations from the IPCC AR5 database with a greater than 66% chance of staying Below 2°C.
- Technology costs are assumed to have declining installation and operational costs per MW as well as quality improvements of RE technologies. Grid parity is achieved for most wind and solar installations in the 2020s on LCOE basis, and most mainstream RE is significantly less costly than fossil generation by 2050.
- Coal and natural gas prices follow the indexed development of the IEA World Energy Outlook 2017 New Policies scenario in the Stated Policies scenario, and the IEA's Sustainable Development scenario in the Below 2 °C.
- Coal is constrained to 1 billion tons by 2050.

A quick overview of the 2050 energy system

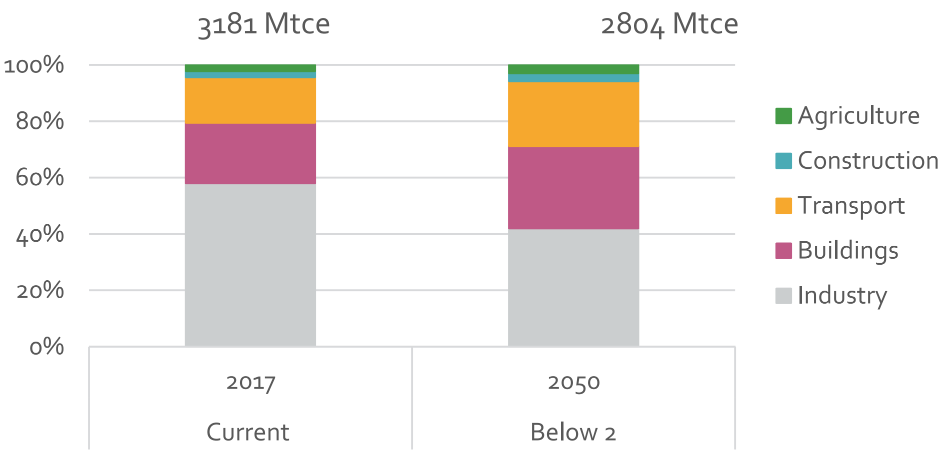
Based on the above-mentioned criteria the 2050 energy system can be described broadly as follows based on our Below 2 °C scenario. Greater detail is provided later in this summary and in the outlook chapters.

Lower final energy consumption and much more electricity in industry and transport sector

Due to the transformation of the Chinese economy, massive focus on energy efficiency and electrification of industry and transport sector the final energy consumption in 2050 is lower than in 2017 and the distribution on energy sources is much different.

Energy efficiency measures bring final energy consumption to 56% of consumption without increased end use efficiency by 2050 (down from 5045 Mtce). Ensuring efficient system integration of variable renewable energy is the primary power system development challenge.

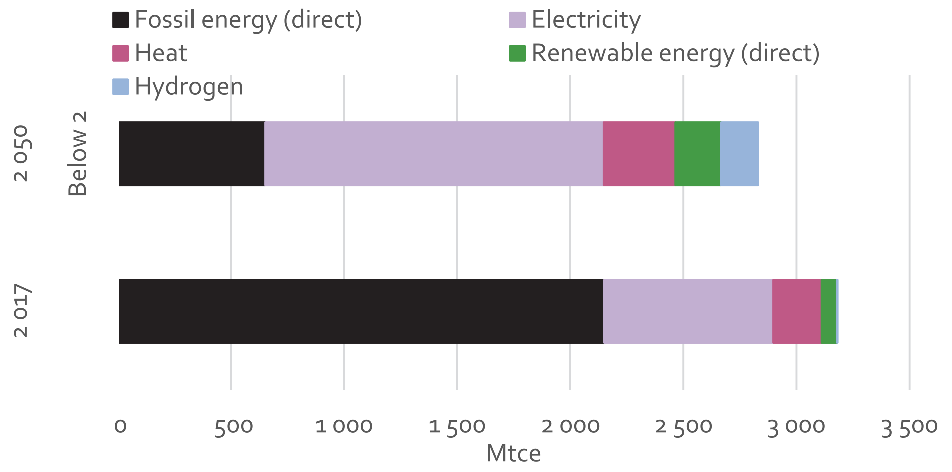
Figure 4: Final energy consumption on different sector in 2017 and 2050



Renewable energy replaces fossil fuels in the energy supply

The energy supply in 2050 is dominated by renewable energy, mainly wind and solar in the power sector. Coal consumption is reduced to a minimum, allowing for flexible use of the coal power plants. Oil is confined mainly to the transport sector and reduced through electrification despite significant higher transport activity in 2050. Natural gas does not play a big role in the energy supply in 2050 since it is too expensive compared with renewable energy sources. Hydro and nuclear power deliver a steady power production although both energy sources are limited in potential and siting possibilities.

Figure 5: The shares of different energy sources in the final energy demand



The transformation of the end-use sectors and the supply system in combination with energy efficiency measures give a completely different energy balance in 2050 compared with the 2017 situation as illustrated in Figure 2 and Figure 7. Transformation losses have been reduced significantly, and renewables and electricity dominate the supply.

Figure 6: The primary energy consumption in 2050 in the Below 2 °C scenario compared to the 2017 (left) and the composition of renewable energy sources in 2050 in the Below 2 °C scenario (right)

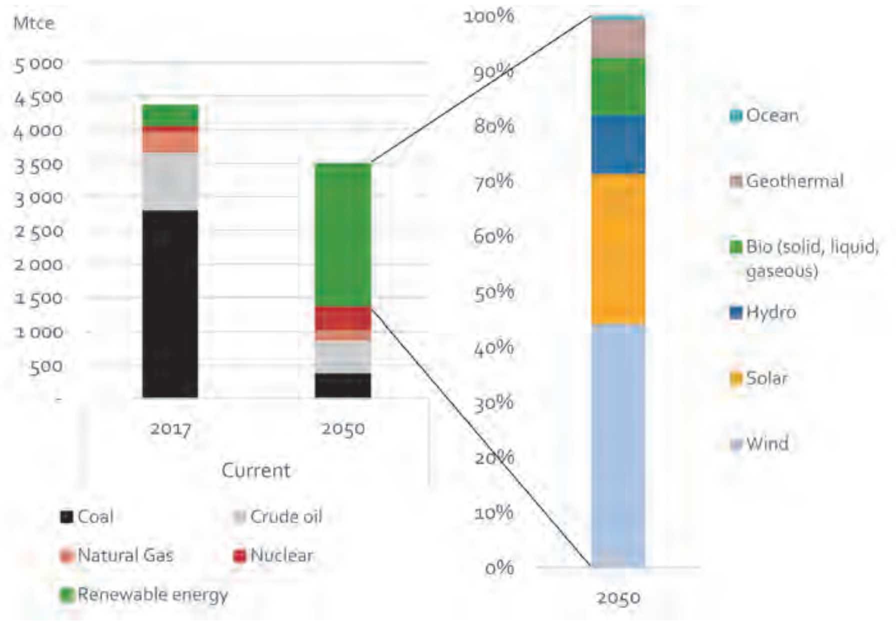
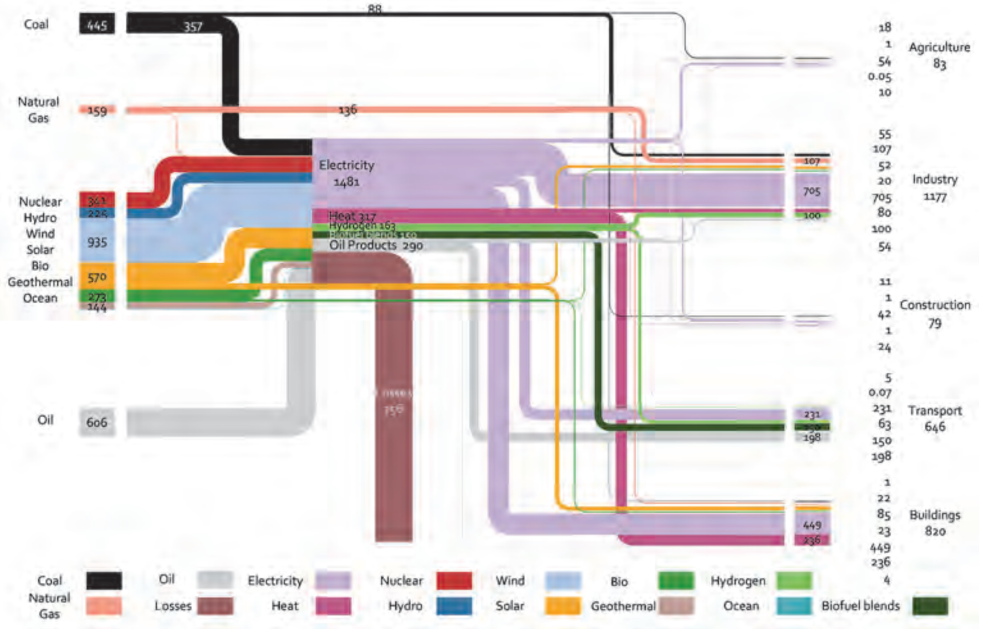


Figure 7: China's energy balance (Mtce) in 2050 in the Below 2 °C scenario



Power economic generation in 2050 points to renewable electricity

In 2050 wind and solar will be the cheapest and most abundant sources of electricity – indeed, they likely already are, considering external costs – and the infrastructure and policies will be in place to ensure they can form the core of the power system.

Ensuring efficient system integration of variable renewable energy is the primary power system development challenge.

Wind and solar dominate future generation investments by default

Coal must peak in the short- or mid-term to meet air quality and climate goals. The price of gas, and dependence on imported gas, limits its development, and in the long-run so does its associated carbon emissions. Hydropower development is slowing due to environmental impacts and increasing investment cost. Biomass resources are scarce, and several other applications have higher value than power generation. Geothermal resources and development costs are uncertain, and ocean energy is in its infancy. Nuclear is restricted to coastal areas for safety reasons.

The power system in 2050 is dynamic and radically different from today's

Characteristics in terms of mix of assets, dispatchability, operational paradigm, cost structure, operational timescales, and topology, will transform. The system cannot be operated according to today's principles, using today's sources of flexibility nor today's regulatory paradigms. Every aspect of the power industry will reinvent itself, from market designs and regulatory setups, to product and service definitions, to stakeholder roles. Converging on the 2050 power system will require substantial investments in new software alongside the hardware. Power system planning, innovation and reform must be forward-looking, and be able to manage uncertainty, variability and increasing complexity.

Figure 8: Levelised costs of electricity generation (LCOE, in RMB/MWh) in 2050

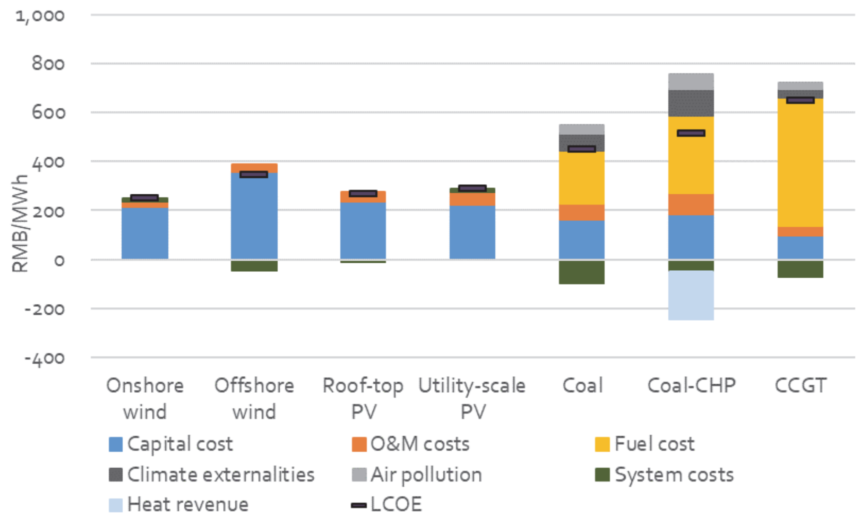
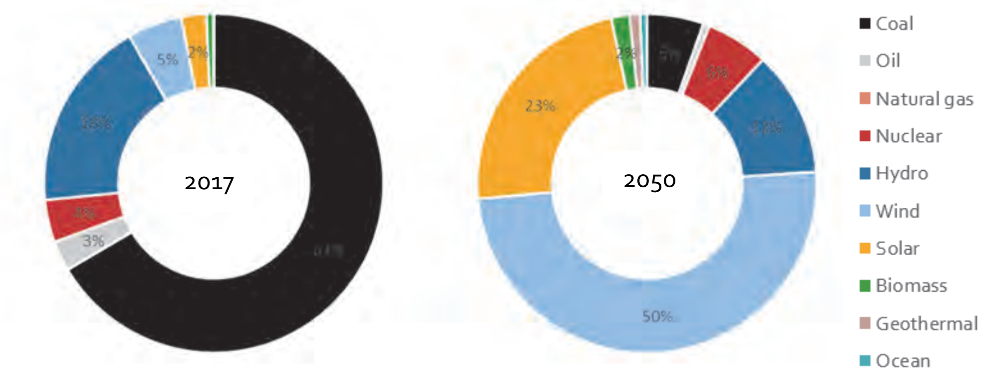


Figure 9: China's power generation mix in 2017 and 2050

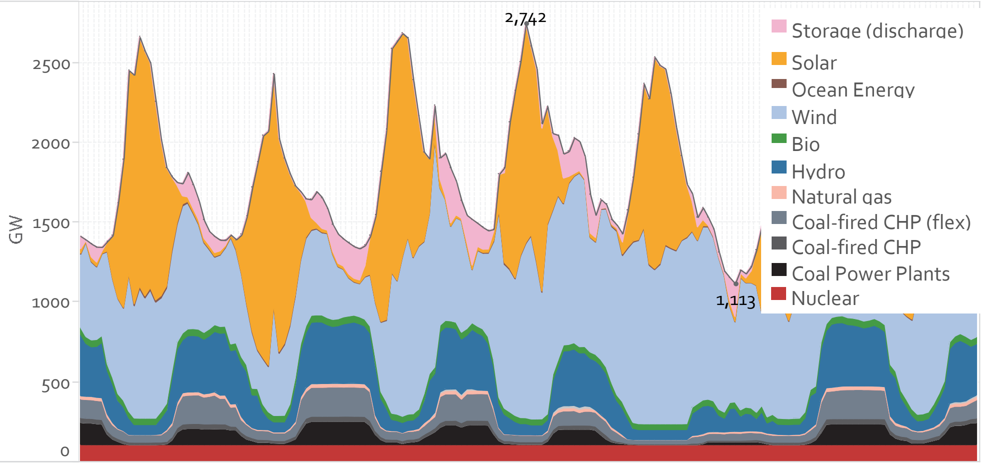


Balancing the system in 2050 requires optimal use of flexible resources

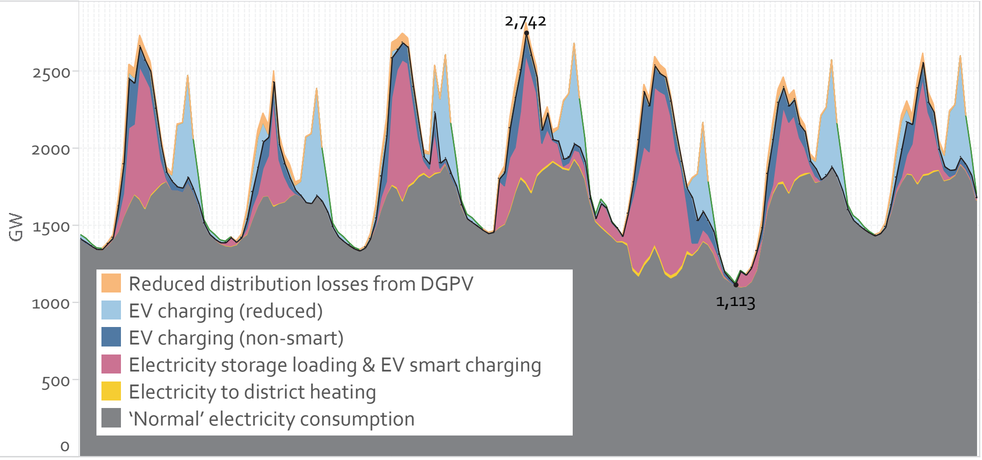
Reliability will depend on greater sharing of resource between regions, through a strong grid and advanced coordination between grids. Reliability will also depend on introducing variety of power sources, that can reduce the risk of failure due to weather related technical failures and shortage of resources and fuels.

Figure 10: Hourly balance of supply and in China's power system in for a week in 2050.

Generation



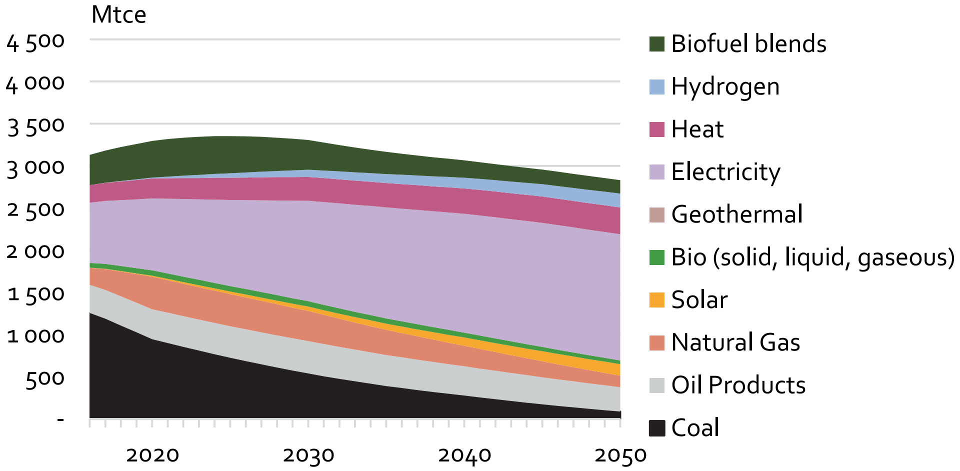
Consumption



The development pathway

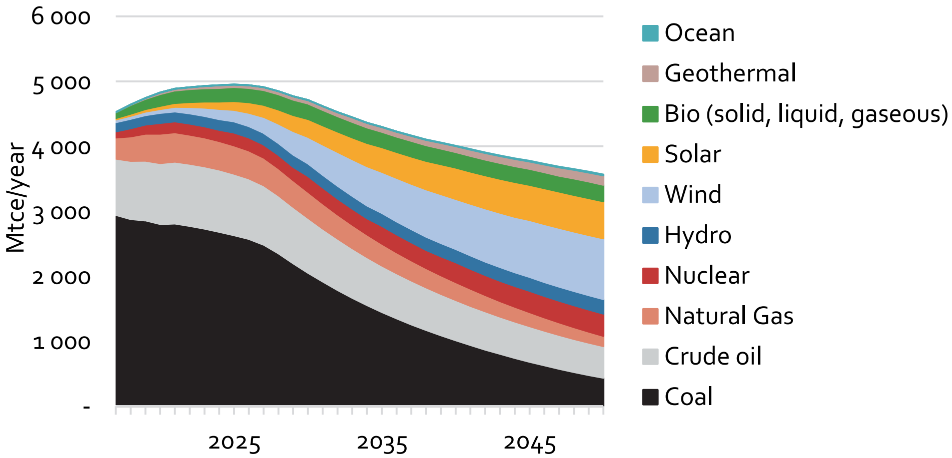
To achieve the visions for 2050, the energy system must change rapidly in the coming years. In the Below 2 °C scenario coal is phased out of the end-use sectors onwards from now, electricity consumption increases rapidly from the mid-2020s, the use of oil (including oil products blended with biofuel) decreases throughout the period, and hydrogen (produced using electricity) is introduced as a new secondary fuel in the industry and transport sectors.

Figure 11: Total Final Energy Demand from 2016 to 2050 in the Below 2 °C scenario



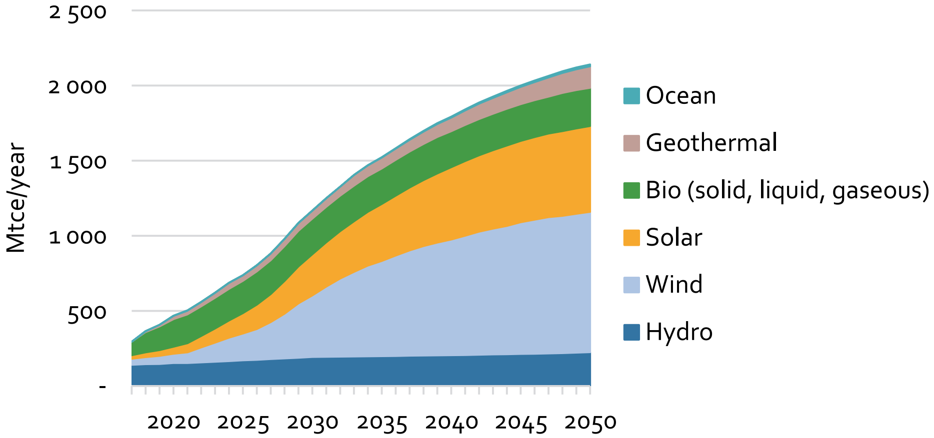
Primary energy demand peaks before 2025 and wind and solar gradually become the dominant energy sources in the energy system (see Figure 12). Coal consumption is reduced throughout the period with an accelerated phase-out from the late 2020s. While Natural gas increases in the short term, it does not play a major role as a bridging fuel between coal and renewable energy, since renewable energy quickly becomes economically more attractive than natural gas in the power sector.

Figure 12: Total Primary Energy Demand (Mtce) from 2017 to 2050 in the Below 2 °C scenario



Renewable energy, especially wind and solar, is deployed throughout the period, most rapidly in the late 2020s, as shown in Figure 13.

Figure 13: Renewable energy production (Mtce) from 2017 to 2050 in the Below 2 °C scenario



Key figures for the milestone years is shown in Table 1 and Table 2.

Table 1: Key figures on Total Primary Energy Demand and Total Final Energy Demand for the Below 2 °C scenario in 2017, 2020, 2035 and 2050

		Current	Below 2		
	Unit	**2017**	**2020**	**2035**	**2050**
Total Primary Energy Supply	**Mtce**	**4 360**	**4 640**	**4 167**	**3 483**
Coal	**Mtce**	2 806	2 648	1 351	387
Crude oil	**Mtce**	864	939	716	487
Natural Gas	**Mtce**	306	441	334	164
Nuclear	**Mtce**	96	165	274	341
Renewable energy	**Mtce**	288	448	1 492	2 105
Hydro	**Mtce**	142	153	199	225
Wind	**Mtce**	40	61	634	935
Solar	**Mtce**	22	47	378	570
Bio (solid, liquid, gaseous)	**Mtce**	83	165	206	218
Geothermal	**Mtce**	0	22	72	144
Ocean	**Mtce**	-	0	3	12
Total Final Energy Demand	**Mtce**	**3 178**	**3 283**	**3 134**	**2 805**
Coal	**Mtce**	1 188	945	391	88
Oil Products	**Mtce**	341	356	367	290
Natural Gas	**Mtce**	247	384	297	136
Solar	**Mtce**	4	11	73	137
Bio (solid, liquid, gaseous)	**Mtce**	59	65	63	44
Geothermal	**Mtce**	-	-	-	-
Electricity	**Mtce**	744	852	1 311	1 481
Heat	**Mtce**	214	238	288	317
Hydrogen	**Mtce**	3	10	107	163
Biofuel blends	**Mtce**	378	422	237	150

Table 2: Installed power generation capacity and total electricity generation for the Below 2 °C scenario in 2017, 2020, 2035 and 2050

			Below 2		
	Unit	**2017**	**2020**	**2035**	**2050**
Total power generation capacity	**GW**	**1 746**	**2 108**	**5 366**	**6 814**
Renewable	**GW**	621	842	4 362	6 159
Hydro	**GW**	313	343	454	532
Wind	**GW**	163	221	1 826	2 664
Bio (solid, liquid, gaseous)	**GW**	15	48	64	57
Solar PV	**GW**	130	224	1 962	2 803
Solar CSP	**GW**	0	5	38	33
Geothermal	**GW**	0	1	5	20
Ocean	**GW**	-	0	13	50
Nuclear	**GW**	36	58	96	120
Fossil fuels	**GW**	1 088	1 208	907	536
Total electricity generation	**TWh**	**6 313**	**7 859**	**13 324**	**15 324**
Renewable	**TWh**	1 676	2 186	9 545	13 488
Hydro	**TWh**	1 153	1 249	1 622	1 831
Wind	**TWh**	328	496	5 159	7 612
Bio (solid, liquid, gaseous)	**TWh**	44	146	221	268
Solar PV	**TWh**	151	277	2 380	3 439
Solar CSP	**TWh**	0	14	100	86
Geothermal	**TWh**	0	4	38	153
Ocean	**TWh**	-	0	26	100
Nuclear	**TWh**	257	442	735	915
Fossil fuels	**TWh**	4 381	5 231	3 044	920

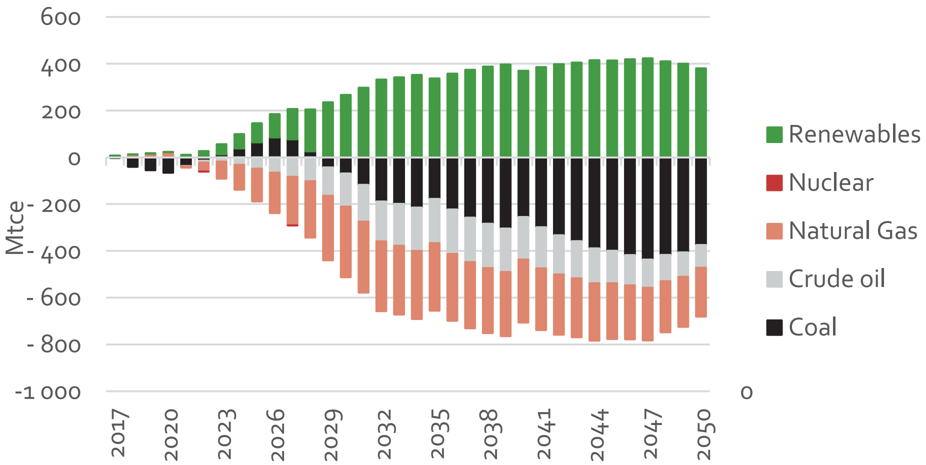
The Stated Policy scenario

The Stated Policy scenario is based on the current and stated policies regarding the energy transition, climate policy and environmental policy. Compared to the Below 2 °C scenario, the main differences in the assumptions and target setting are:

- More ambitious targets for CO_2 reduction in the Below 2 °C scenario to ensure compliance with a below 2 °C increase in global temperature
- Targets for use of natural gas until 2030 in the Stated Policy scenario, while the Below 2 °C scenario has no targets after 2020.
- Increased emphasis on electrification of end use consumption.

As a result, the Stated Policy scenario has a lower deployment of renewable energy after 2020, and a higher consumption of coal, oil and natural gas than the Below 2 °C scenario as shown in Figure 14, and the electrification of end-use consumption is also less than the Below 2 °C scenario.

Figure 14: Differences in Primary Energy Demand (Mtce) between the Below 2 °C scenario and the Stated Policy scenario towards 2050



Compliance with the Beautiful China energy system visions

The quality of the two scenarios is measured by their ability to fulfil the policy visions for the energy system in 2050 – building a clean, low-carbon, safe and efficient energy system.

Clean 2050 system in both scenarios, but cleaner pathway in Below 2 °C scenario

Air pollution from the energy system falls substantially by 2050 in both the Below 2 °C and the Stated Policies scenarios on all air pollution parameters except for ammonia ($NH3$), which originates mainly from the agricultural sector. However, the Below 2 °C scenario projects a faster reduction of air pollutants than the Stated Policies scenarios. Black carbon (BC), organic carbon (OC), nitrogen oxides (NO_x), sulphur dioxide (SO_2), carbon monoxide (CO), and non-methane volatile organic compound (NMVOC) emissions are all lower in the Below 2 °C scenario in the 2030s due to the earlier reductions of coal and oil use in this scenario. This leads to relative reduction in pollution related cases of serious illness and premature mortality, resulting in significant socio-economic benefits.

In both CREO scenarios, total water consumption for energy falls despite a doubling of power production due to improvements in technology. Energy sector water consumption in the Below 2 °C scenario is much lower than in the Stated Policy scenario. In the Below 2 °C scenario, water consumption is reduced from 2020, while the Stated Policies scenario sees increased water consumption until 2030 after which it declines.

Significant CO_2 reduction in both scenarios

In its design, the Below 2 °C scenario sets a limit on total CO_2 emission from 2017 to 2050 of 230 billion tons, aiming for China to provide a significant contribution to meeting the Paris agreement goals. Based on the allowable accumulated emissions, an annual CO_2 budget is established to ensure a smooth reduction from today's level to the 2050 level. The largest reduction in CO_2 emission is in the industrial sector, which is due to its extensive electrification. The power and district heating sectors also realise significant carbon emissions reductions despite doubling in electricity consumption.

Figure 15: Energy related CO_2 emissions in the Below 2 °C scenario 2017 – 2050 on sectors

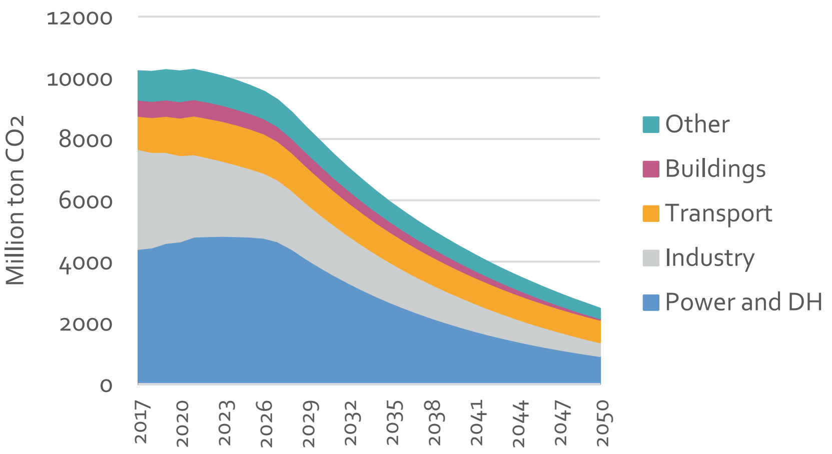
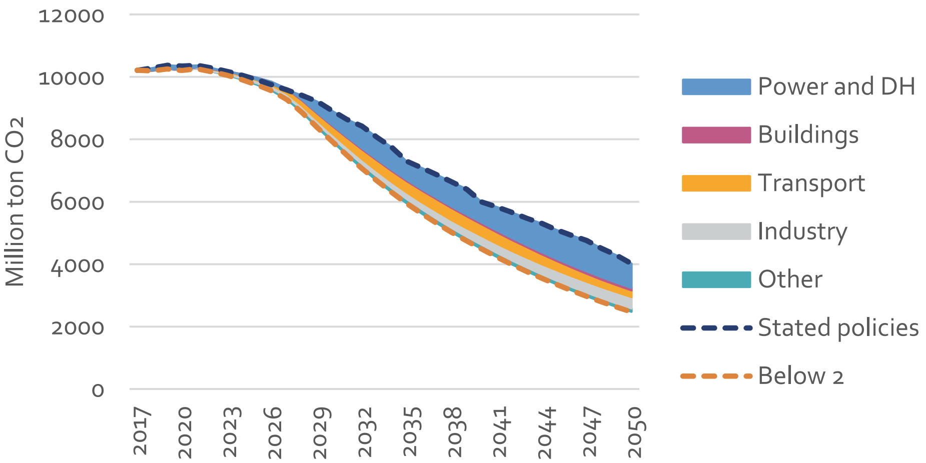


Figure 16: CO_2 emission and differences between Below 2 °C scenario and Stated Policy scenario 2017 – 2050



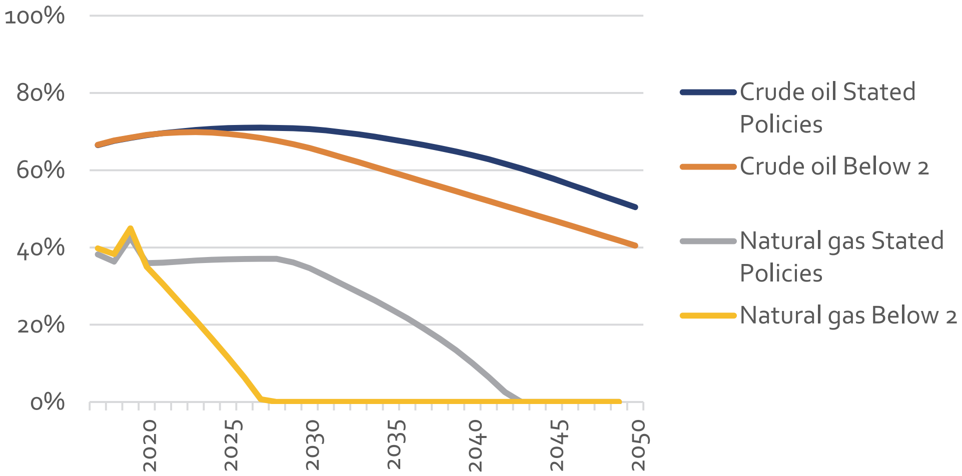
The Stated Policies scenario is less ambitious in terms of CO_2 emission reductions and does not comply with the CO_2 cap. Compared to the Below 2 °C scenario, the power sector has higher emissions.

Dependence on imported fuels significantly reduced

The energy system in 2050 is much more diverse in terms of the mix of different energy sources compared to the situation today, where coal and other fossil fuels dominate the energy supply. Dependence on fossil fuels declines to 40% in the Below 2 °C scenario and to 50% in the Stated Policy scenario.

Dependence on fuel imports is reduced in both scenarios as well. The Below 2 °C scenario has a quicker and deeper import reduction than the Stated Policies scenarios for both oil and natural gas, which constitute the main import challenge.

Figure 17: Import share of oil and natural gas in Below 2 °C scenario and Stated Policy scenario



More efficient use of energy

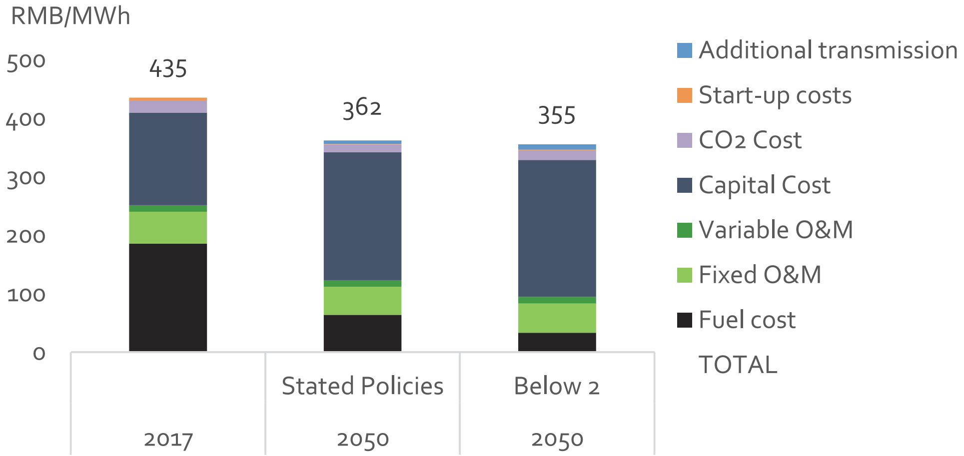
By 2050, China's primary energy consumption is only 80% of the 2017 consumption in the Below 2 °C scenario. Meanwhile, the gross domestic product (GDP) quadruples and energy intensity improves greatly.

In the two scenarios, energy efficiency offsets increasing demand for many end-uses. It compensates for the inertia in the industrial supply chain and enables the system to radically shift the energy mix. Increased efficiency also mitigates energy consumption growth in the buildings and transport sectors and flattens the upwards trends in final energy consumption between 2017 and 2050. On the supply side, the shift from coal-based thermal power plants with high losses to renewable energy without major transformation losses add to the energy efficiency of the entire energy system.

Cheaper electricity in the future

Due to continued cost reductions in renewable energy technologies and the gradual retirement of uneconomical assets, it is possible to supply electricity at lower cost than today. In both scenarios the cost of electricity supply is lower in 2050. The more stringent focus on CO2 emissions reductions in the Below 2 °C scenario promotes a more rapid transition to an energy system based on renewable energy. As a result, society spends less on fuel and relatively more on infrastructure and system-related costs.

Figure 18: Power system costs for 2017 and 2050 in the Below 2 °C scenario and Stated Policy scenario



Job creation and GDP impact

The rapid development of the renewable energy industry will play a positive role in promoting macroeconomic development. From 2025 to 2035, the swift growth of manufacturing scale will boost the demand for employment in sectors directly or indirectly related to renewable energy. This positive effect is greater than the negative effects related to a decrease in employment in fossil energy such as coal and thermal power generation.

The development of the renewable energy industry promotes the overall adjustment of the country's macroeconomic structure. The renewable energy supply chain covers electronic components, information and communication, computers, professional technical services and other industries. These sectors feature high added value and the modernisation of the economy.

Falling costs for renewable energy technologies will increase the operating efficiency of the energy industry. This creates development space for the provision of value-added services such as energy information and data analysis based on basic energy services, distributed energy, energy production and consumption (prosumer) services, energy storage, and EV charging.

Significant progress in Stated Policy scenario, additional benefits in Below 2 °C scenario

In summary, all the criteria for the future energy system is greatly improved both in the Stated Policy scenario and the Below 2 °C scenario. However, from a comprehensive viewpoint, considering energy security, environmental impact and energy system costs, it is worthwhile taking the energy transition one step further than the pathway given by the current and stated policy framework. Hence, the Below 2 °C scenario could be the feasible vision and basis for the coming year's policy making.

Policy measures to promote the energy transition

In Part 3 of the CREO 2018 report several policy measures and crosscutting topics are discussed. Here is a short summary of the key findings in the different chapters in Part 3:

RE Incentives

China aims to change the policies for supporting wind and solar, shifting from fixed-support mechanisms based on feed-in tariffs to more flexible, market-oriented approaches, including auctions and renewable obligations. The changes include:

- Policies that will set renewable obligations for each province based on current renewable development, the renewable potential, and local electricity demand.
- A reform of subsidies for renewable energy, which will include auctions for onshore wind and solar PV, and relatively fixed tariffs for energy sources like biomass and ocean energy that have yet to reach scale. Price competition will be a central element of ensuring subsidies can be phased out, while continuing to promote growth in wind and solar.
- Other market reform measures essential to enabling renewable energy to compete without subsidies. These include reforming transmission pricing to prevent cross-provincial transmission fees and cross-subsidies from impeding export of renewables, adopting distribution grid reforms favourable for developing distributed renewable energy, reforming tax structures (including carbon and land taxes) to reflect external costs of various energy sources, enabling renewable energy (including distributed energy) to participate in spot markets as well as medium- and long-term power markets, and promoting green finance to support development of clean energy.

In this context it is highly relevant to look at international experiences on renewable energy auctions. Germany's auctions have featured strong participation, good project realization rates, and steadily falling prices for winning bids. Key factors in Germany's success include transparent procedural steps, a regular schedule for conducting auctions, regulatory stability to ensure bidders and project financiers have confidence relevant rules will remain in place and emphasizing technology-specific tenders to ensure steady development of the renewable industry. The chapter concludes by describing the characteristics of present auction policies in China and their future development.

Renewable energy in power markets

Progress is being made in China's ongoing power market reform, and 2018 has seen a justified increased emphasis on the development of spot markets. This is a healthy development from the perspective of the integration of renewables. With the penetration of renewable energy increasing the question of how renewable generation should participate in and contribute to the price formation in the electricity market.

We describe how mandatory grid uptake of renewables and feed-in tariff (FIT) projects are the beginning rather than the endpoint of RE development. Renewable energy generation can participate in market trading in financial, day-ahead, intraday, and real-time balancing markets, as well as provide other ancillary services. The way renewables are considered in the market design, can significantly affect their profitability and exposure to market and regulatory risks. A balance should be struck to ensure that the market incentives are there to motivate efficient deployment and operation from a system perspective, while not impeding the energy transition by overburdening RE projects with risks, which translate into higher financing costs and prolong renewable energy technologies reliance on subsidies.

The power system reform has shifted from top-level design to implementation. The electricity market development has been tasked to provincial governments for design and implementation within their administrative jurisdiction. However, the electricity market requires further consensus regarding top-level design elements and a clear implementation path from provincial piloting to a well-functioning and integrated power market in China.

Carbon pricing

Since last year's CREO, the Chinese national pilot for an emission trading system has been set-up for the power sector as a starting point.

This chapter begins with an overview of the current status of China's ETS, summarizes the experiences from Europe on the relationship between ETS and RE support policies, and gives an overview of the most recent changes in the policy setting for the European ETS.

In general, the European case does not involve direct coordination of renewable supports and targets with carbon markets. Instead, the European experience shows that a stability reserve mechanism, combined with retirement of excess allowances, has the potential to avoid excess allowance situations from developing.

The chapter concludes with recommendations for the next step in the further development of the Chinese ETS from a RE promotion policy perspective.

Interconnectors: transmission

The chapter begins with an overview of China's power grid development:

China's grid has expanded rapidly in recent decades to meet demand growth and enable renewable integration. However, China's power grid development has been focused on large-capacity and long-distance UHV transmission, and many existing 500-kV and 750-kV inter-provincial and inter-regional transmission lines have seen low utilization.

China's system also focuses on single-direction transfers of electricity from sending regions to high demand regions, making the system less flexible that it could be. Meanwhile, barriers to trading power between provinces remain high.

Drawing on international experience, the chapter describes how European countries are working to optimize cross-zonal connections under the principle that bottlenecks and constraints should be resolved through investment wherever net positive socio-economic benefits can be achieved. Europe will likely evolve into a highly meshed AC grid with point-to-point connections to a few countries in the North and South, plus highly-flexible DC interconnectors between regions.

With the European case in mind, the chapter analyses the flexible use of interconnectors in China, showing that increases in grid flexible operation in China leads to substantially lower-cost electricity, reductions in CO_2 emissions, higher renewable energy penetration, and lower curtailment.

The role of distribution grids

In centralized power systems with large thermal power plants, distribution grids are used to distribute electricity from the transmission grid to end consumers like households. In energy systems with increasing shares of RE, the role of distribution grids changes since they also become the connection point for the electricity feed-in of distributed generators. Power flows will become increasingly bi-directional, creating the need for new concepts to address the technical and procedural challenges that result from this change. The chapter describes briefly the situation in distribution grids in China, noting the following key points:

- China has increased the automation of its distribution grid somewhat, but the potential for improvement is still very large.
- The distribution grid still suffers from relatively low reliability.
- The distribution grid is unable to cope with high levels of small-scale distributed energy, storage, and electric vehicles.

As a result, China needs to rapidly upgrade and modernise distribution grids with smart grid technology, create policies to incentivise distribution grid operators to accept more distributed energy, and improve distribution grid pricing and business models to this end.

Demand side response

Due to the volatility of power generation from RE, more flexibility is needed in the power system in order to better integrate renewable energies and to ensure the stability of the power system. With flexible processes, energy consumers can contribute to the system integration of renewable energy. This chapter introduces the international cases of Germany and France regarding the use of DR in a market context, describes the current framework for the use of demand side flexibility in China, and offers suggestions for further action.

Successful implementation of demand response depends on full implementation of ongoing power market reform in China, including establishing markets for spot markets in wholesale power markets, as well as retail markets.

Demand response also depends on long-term and short-term price signals, and on whether all relevant parties can benefit from compensation for adjusting demand to reflect these price signals. Unbundling grid operation and retail sales could help resolve conflicts of interest that currently prevent efficient transmission of wholesale price signals to retail users.

Given the complexity of DR, stakeholder involvement is also critical. Stakeholders such as large industrial customers, aggregators, grid companies, and generators all need to understand the framework for DR and who can benefit and participate. This may require marketing campaigns, educational efforts, and pilots for industrial customers to gain and share experiences.

Heating

Given its situation with many large, dense cities, and high variety in potential waste heat providers and customers, China may opt for a regulated heat planning approach including environmental and climate benefits of heat planning. For rural areas, where unabated coal heating is still common, heat pumps and solar heating may offer the best solution. For cities, including small- and medium-sized cities, district heating may be the best option. Currently, waste heat from many power and industrial processes is wasted in cooling towers. While China has plans to expand combined heat-and-power, China could go beyond CHP and create integrated markets for heating and power. In particular, we suggest:

- Variable wholesale and retail prices for both heating and power are necessary to prevent market failures, such as curtailment of renewable energy in winter. With market incentives, district heating can become an efficient heat "battery" to store heat for when it is needed.
- In cold and severe cold areas and even in temperate areas district heating supply should be measured and delivered for both heating and domestic hot water supply all year.
- In areas with hot summers and cold winters and even in areas with hot summers large buildings should be equipped with ventilation systems, which can be heated in winter via district heating and cooled in summer with absorption heat pumps supplied with heat from district heating.
- Ensure energy and environmental taxes are applied efficiently at the level of units of emissions and fuel, to prevent double-counting of environmental attributes and effective price signals of external costs to users of heat and power.

Offshore wind

China has ample offshore wind potential, but offshore wind development has lagged onshore wind and solar growth for several years. China's offshore wind projects have shown lower output than projected given available wind resources, and China's process for selecting offshore wind sites and project developers appears cumbersome and lacking in transparency. These failings have helped drive up the price of electricity from offshore wind, further slowing the development of this resource.

This chapter draws on international experience, particularly in Denmark, to present various suggestions on how to improve on the present pattern of offshore wind development in China, including the following:

- Carry out a thorough screening and planning before designating areas for offshore wind turbines, accounting for wind conditions, sea depths, grid connection options, seabed conditions, and marine life. Regulators should then rank the potential projects based on expected economic performance given these conditions and limitations.
- Developers should have greater flexibility to design the wind farm and choose foundations, turbines and other components, without local content requirements that can prevent innovation or restrict price competition for components and services.
- Involve all affected parties with interests at sea at government level already at the beginning of planning to avoid future conflicting interests. Consider clarifying competing interests such as shipping routes, environmentally sensitive sites, fishing areas, resources and extraction up front in planning.
- Employ existing studies on environmental impacts in the public domain before requiring expensive and time-consuming analysis as part of the EIA requirements. If no such resources are available, set up a general framework for environmental impact assessments (EIAs) and ensure their results are public for the benefit of future offshore wind planning.

Key recommendations

Based on the analyses in CREO 2018, the following actions are recommended.

Coal and oil reduction measures

The single most important step now is to reduce coal consumption in China. The following measures are proposed:

Keep coal reduction as a key priority via strict controls

The decisions and targets for coal reduction must be enforced strictly to avoid stranded investments and reduce vested interests in a continuation of high coal consumption.

Stop new coal-fired power plants now

Investments in new coal power plants are unnecessary for a long period and such investments have a high risk of turning unprofitable. New coal plants also lower the profitability of previous investments by reducing the utilisation of existing power plants and maintaining the curtailment of wind and solar power. A moratorium on new coal power plant construction should be introduced immediately.

Reduction of coal use in industry by sectoral rebalancing and electrification

In the next years, cutting excess capacity in heavy industry and destocking property inventory should be promoted to ensure a decrease in demand for coal in industry. In addition, electrified steel-making and green cement production technologies should be promoted to further phase out the majority of the remaining coal demand.

Stop growth in oil consumption by encouraging ambitious deployment of EVs in the transport sector

The increasing import dependence for oil should be stopped via a continued effort to deploy electric cars in the transport sector.

Ensure a sufficiently high cost on CO_2 emissions, also in the short run

To build a low-carbon energy system a strict CO_2 cap on the energy sector is needed. Efficient carbon-pricing could be one way to include the costs of CO_2 emissions in the power price and thereby create a more level playing field between fossil fuel based power and renewable energy. The announced national pilot for CO_2 emissions from the power sector currently seems insufficient to ensure a high enough carbon price. Further measures should be considered as short-term solutions, including a carbon tax and/or a floor-price within the carbon market. In addition, carbon-pricing and carbon markets must include other sectors beyond the power sector, particularly as coal consumption is also large in the industrial sector.

Raise deployment of renewable energy to a new level in the next decade

According to the undertaken analyses, the 14th and 15th Five-Year plan periods should have significantly higher deployment levels of solar and wind power than the 13th Five-Year Plan period. This will further accelerate the economic viability of renewable energy compared to fossil fuel technologies. However, renewable energy remains vulnerable to policy choices, and it is important to focus on removing barriers for RE deployment and set incentives to encourage investors and developers to accelerate this massive effort. The following short-term measures would help move in this direction:

Clear guidance for power system development

The moratorium on new coal power plant development should be followed by clear signals for promoting renewable energy. Absence of firm power sector reform implementation would impede necessary RE scale-up. Implementation of power market reform, including spot markets with expanded access for renewables, full technical flexibility of the existing coal fleet, shifting renewable installation to low curtailment areas, and completion of planned transmission corridors should enable resolution of curtailment by 2020, in line with government targets. This is imperative for renewable development in the 14th Five-Year Plan period, and any worsening of curtailment would risk stalling renewable energy cost reductions and jeopardise China's long-term clean energy targets. To reach a pathway to achieving the Paris agreement, the Below 2 °C scenario projects non-fossil electricity should reach 44% by 2025. In the 14th FYP period, annual solar PV installation should achieve 70-85 GW per year and wind 40-70 GW per year on average.

China should target non-fossil power generation to account for about 77% by 2035, and for renewable generation to supply at least 67%. Consequently also, the 50% non-fossil power generation target for 2030 should be increased.

Flexibility services should be valued, priced, and commercialised. Supply and demand sides provide different kinds of flexibility services, with efficient signals from power market.

Grids and power markets should be increasingly interconnected, dynamically operated, according to the imminent needs of the system. Diverse flexibility resources will allow more efficient integration of renewables and faster reduction of CO_2 emissions. With the reductions in storage costs, 400-600 GW of accumulated storage capacity could be in the system by 2035. With increasing electrification, the demand side can increasingly provide flexibility, and smart charging of electric vehicles can play a central role in ensuring the system balance.

The key players in the power sector transformation must be the driving forces for the deployment of renewables. The large power producers should adapt their strategies for the future, the grid companies should adapt their planning of transmission for the new era, and local governments should play an active role in the transition from coal to renewables. The implementation of power sector reform will have a decisive role for creating the proper incentives for all stakeholders.

Remove barriers for distributed generation and offshore wind

Deployment of renewable energy near energy load centres should be promoted via development of a smoother approval process. This requires stronger coordination between ministries and between central and local governments to remove institutional barriers for renewable energy. The off-shore wind planning and approval process should also be streamlined through better coordination between authorities.

Gradually shift the subsidy system to avoid stop-go situations

A firm and clear pathway for transformation of the subsidy system for renewables will assist developers in project planning and implementation and reduce the potential risks for investors. Utilisation of auctions for large renewable energy projects could further reduce costs, while a stringent implementation of the renewable energy quota system would provide key players with a more central role in deployment and reduce the need for a continuation of feed-in tariffs.

Part 1: Energy Transition Status

1 Global energy situation

The development of the energy situation the recent years is complex and gives mixed signals for the future development trend. Renewable energy and energy storage have continued to fall in price, and clean energy development has become a global trend, with booming investments. However, these technologies currently remain a small segment of world energy production and consumption. Overall, world energy use continues to rise, and carbon emissions continue to rise as well. At the same time, the world continues to witness increasing immediate evidence of climate change, including accelerated ice-sheet melting in Greenland, more severe and slow-moving hurricanes and typhoons in the Pacific and Atlantic, and increased global average temperatures.

In this section, we note some of the most important global developments: the increased recognition of the difficulty in meeting the Paris Climate Agreement target of keeping global temperature change below 2 degrees Celsius, the holding of COP23 in Bonn and the agreement there on a stock-taking process, increased world energy price volatility associated with geopolitical instability, the release of new world energy forecasts with greater ambitions for expanding the production of cheap, renewable energy, and finally the new trends in business strategies moving from pure economic focus to a broader focus on economic long-term sustainability and environmentally sound solutions.

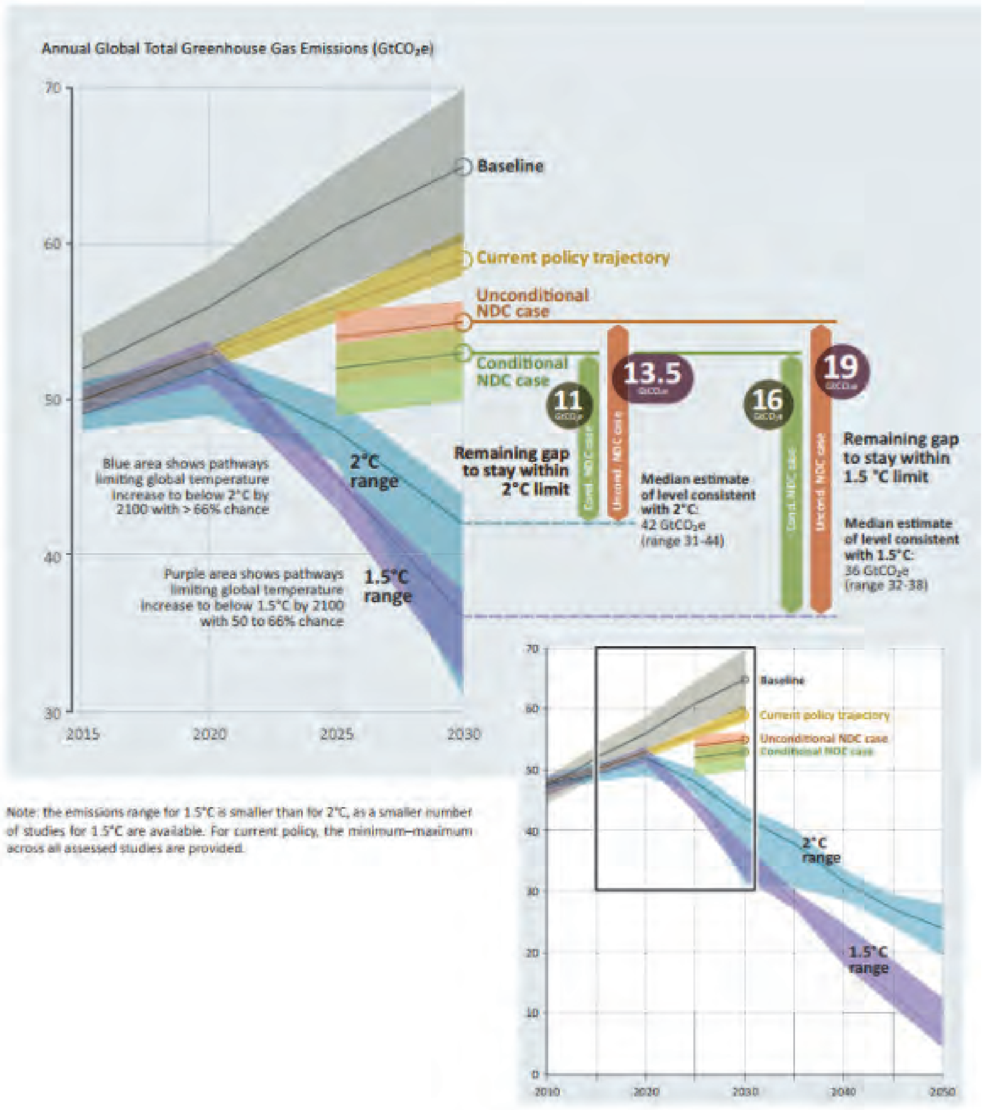
1.1 Climate concerns are driving the energy transition

The concerns about the dramatic and irreversible consequences of global rising temperature caused by greenhouse gasses are among the strongest drivers for the ongoing energy transition. It is now three years since the Paris agreement was signed and two years since it formally entered into force and the work since then illustrates how difficult it is to change the energy system and the emissions from the energy sector sufficiently fast to reach the climate goals.

The world is not on track to meet Paris targets

According to the Global Emissions Gap report, published by the United Nations in 2017, the current national commitments and policies now in place are consistent with approximately 3-3.2 degrees C increase in global average temperatures by 2100, insufficient to prevent the most catastrophic impacts of climate change.[1]

Figure 1-1: Global greenhouse gas emissions under different scenarios and the emissions gap2



Note: the emissions range for 1.5°C is smaller than for 2°C, as a smaller number of studies for 1.5°C are available. For current policy, the minimum–maximum across all assessed studies are provided.

Recent COP23 advanced efforts to take stock of progress and "enhance ambition"

While the world has made insufficient progress in achieving climate goals, world leaders do appear to recognize the need to update policies and plans more frequently. This entails more frequent "stock-taking" as well as, very likely, modification to national policy plans.

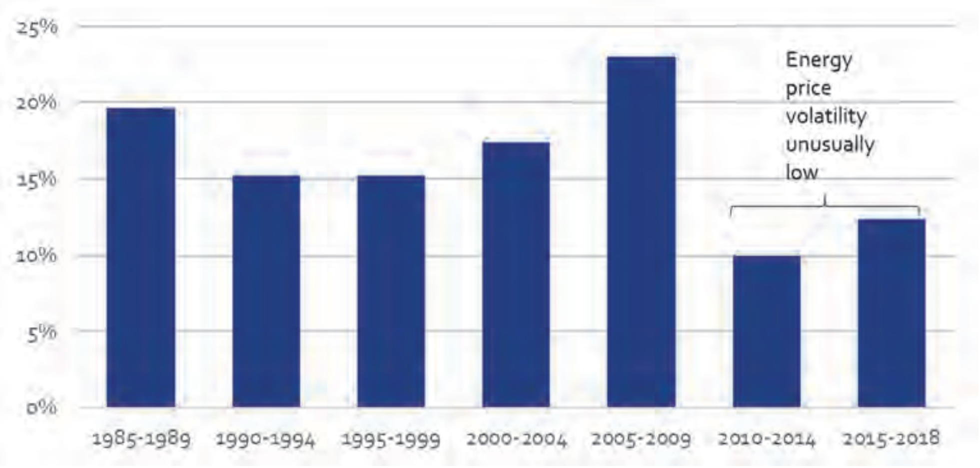
COP23 was held in Bonn, Germany, in November 2017. The meeting was the second COP to be held since the signing of the Paris Climate Agreement, and the first since U.S. President Donald Trump announced his intent to withdraw from the Paris agreement. At the COP in Bonn, countries agreed to reinforce stock-taking efforts, working towards implementing the Paris agreement provision that there should be a one-off moment in 2018 to take stock of how climate action was progressing. This information will be used to inform the next round of nationally-determined contributions (NDCs), due in 2020. Additional stocktaking sessions in 2018 and 2019 will review progress on meeting prior commitments to reduce emissions prior to 2020. Originally called the "facilitative dialogue," the name of this one-off process in 2018 was changed to "Talanoa dialogue" under the Fijian COP presidency. This name reflects a traditional approach to discussions used in Fiji for an "inclusive, participatory and transparent" process.

Some countries are choosing to act ahead of coming stock-taking rounds to update action plans. The phrase "enhanced ambition," applied to updated country plans and private sector commitments, could help implement the Paris Agreement's longer-term "ratchet mechanism," which aims to increase ambition on a five-year incremental cycle. There are some indications that China may have room to increase its ambition given developments on the policy and economic level over recent years, which would help bring the collective global NDCs closer to what would be needed to meet the Paris Agreement targets. In June 2018, China's NSCS published a study stating that "China has the potential and conditions to ratchet up its NDC." [3]

1.2 Energy price volatility could return

In the first half of 2018, oil price volatility has picked up, partly due to geopolitical instability, among other factors. Rising oil prices affect oil importing countries in several ways, including worsening trade balances, raising the price of other related goods such as imported liquefied natural gas and chemical products, and leading to greater investment uncertainty in energy-dependent sectors. In countries with regulated retail fuel prices, rising global energy prices can lead to greater fiscal outlays for fuel price subsidies, meaning less money available for other needed services. This may be particularly relevant in China, given commitments to reduce fossil fuel subsidies—and recent decisions to phase out or eliminate subsidies for clean energy technologies such as solar and electric vehicles.

Figure 1-2: World oil price volatility since 1985 [4]



Note: Standard deviation of daily oil price as percentage of average daily price for Cushing, Oklahoma oil futures, in US$ per barrel.

Aside from the immediate causes of 2018 oil price volatility, policymakers should recognize that oil price volatility could return to more normal levels over the coming decades. In the period from 1985 to 2009, which excludes the major oil shocks of the 1970s and 1980s, oil prices showed fluctuations considerably higher than experienced since 2010. Indeed, oil price volatility in 2005-2009 was roughly twice the volatility of the period since 2010. Rising oil prices and increased volatility underscores the need for policymakers to plan for greater domestic energy production—especially from cleaner sources that aren't exposed to world energy prices—as well as greater efforts to electrify sectors affected by oil and gas imports.

1.3 Renewable energy continues to grow worldwide

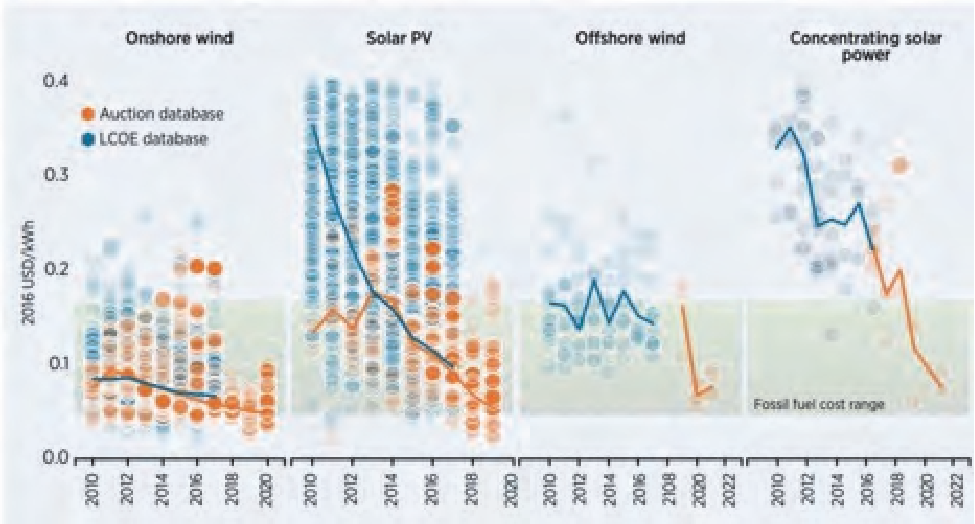
Overall, renewable energy continues to exhibit strong growth worldwide, particularly in wind and solar. Solar PV capacity grew worldwide by almost 100 GW, or 32%, while wind capacity grew by 52 GW or 10.6%. Together, wind and solar dominated worldwide new capacity additions, outpacing coal and natural gas in terms of new GW added to the grid. Other renewable energy sources, including hydropower, biomass power, and biomass transport fuels, saw more modest growth. Although investment in renewable energy and fuels remained roughly constant, this partially reflected falling costs for wind and solar. [5]

Variable wind and solar PV continue to reach new heights in terms of power mix in many countries. In Europe, Denmark derived 52.9% of electricity from wind and solar in 2017, while Germany obtained 26%. Also in the developing world VRE began to capture impressive shares of electricity consumption, such as 28% in Uruguay.[6] Honduras and Nicaragua, two least-developed countries (LDCs) in Central America, obtained nearly 20% of electricity from wind and solar. On an instantaneous basis, wind and solar delivered impressive results in several regions such as Texas (54% from wind and solar, combined), Germany (66% from wind and solar, combined), and South Australia (100% from wind alone and 44% from solar PV alone).[7]

In 2017 China continued to dominate world wind and solar installations. For solar, China accounted for 54% of global PV capacity additions. Though China wind capacity additions fell in 2017 versus prior years, the country nonetheless accounted for 37% of global new wind capacity. Of the 1,034 GW of non-hydro renewable capacity worldwide, China accounted for 334 GW, or almost one-third. Even assuming China wind and solar additions decline in 2018 from the prior year, China will likely remain the most important market for these technologies.

As well, China wind and solar manufacturing play a central role in the global clean energy transition, by scaling up manufacturing and thereby lowering prices for wind and solar PV on global markets. 2017 and 2018 showed a continuation in a trend towards lower-cost wind and solar PV additions. Several major markets saw record low bidding prices for construction of wind and solar plants. Though an individual bid may not necessarily accurately reflect expected energy prices from a given technology, in aggregate these patterns indicate that wind and solar have either achieved or are close to achieving price parity with incumbent generation technologies. Indeed, in some regions solar PV matched with storage can even out-compete operating costs from existing coal or gas plants. While wind and solar still benefit from subsidies in many markets, it will soon be feasible to remove these subsidies—an impressive feat given that prices for fossil fuel-derived electricity do not reflect their full external costs.

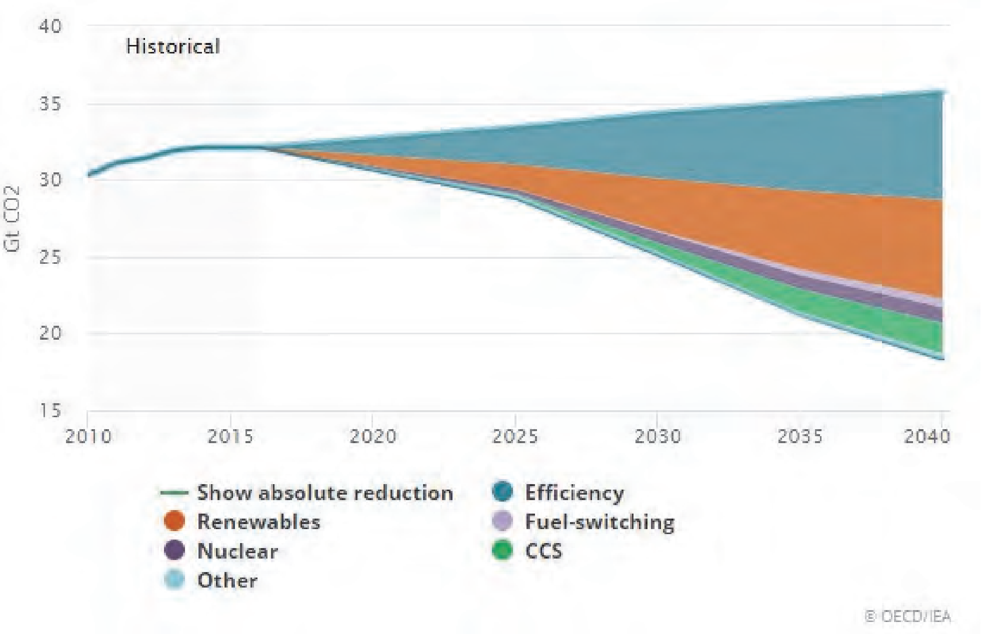
Figure 1-3: Wind and solar energy costs from Irena database[8]



Irena's project database vividly illustrates the rapidly falling project costs for wind and solar. For onshore wind, by 2020 energy costs should fall to US$ 0.05/kWh. Wind power auctions in 2017 showed prices as low as US$ 0.02/kWh for one project in Mexico and US$ 0.03/kWh for projects in India and Morocco.[9] For solar PV, Irena data suggests that energy costs will fall to US$ 0.06/kWh in 2019-2020, although Irena notes that this reflects that many solar PV projects are located in sunny regions such as India, Australia, the Southwest U.S., Mexico, and the Middle East. Recent PV projects in the U.S., Mexico, and the Middle East have offered prices as low as US$ 0.02. Even for offshore wind, where costs had remained stubbornly high for many years, Irena data suggests project costs in the North Sea will fall to US$ 0.06-0.10/kWh.[10]

While the world is still far from the path needed to achieve the Paris Agreement climate goals, progress on wind, solar PV, energy storage, and electric vehicles makes these goals more feasible than before. In 2017, the International Energy Agency (IEA) issued its annual tracking report, this time for the first time noting that progress in these four technologies is now "on track" for achieving Paris. Previously, IEA's tracking reports stated that no sectors were on track. In 2018, the IEA's analysis downgraded wind and energy storage, noting that progress in deployment and technology has slowed and these technologies are no longer on track—whereas LED lighting and data centre networks (both in the efficiency fields) joined the "on track" list. Unabated coal combustion remained the most important technology deemed not on track by IEA.[11]

Figure 1-4: Additional CO_2 emissions reductions in the SDS vs. NPS[12]



While wind and solar PV still account for a small share of world energy production, these technologies are critical for meeting the Paris targets. The IEA's sustainable development scenario, displayed above, suggests that renewable energy should account for almost half the reduction in global emissions needed versus the national policy scenario. Wind currently accounts for just 5.6% of electricity production, and solar PV just 1.9%, as of 2017. All renewable energy, including hydro and biomass, provide just over one-quarter of global electricity production, and about 18% of total final energy consumption.[13] Achieving the Paris targets will require wind and solar to continue to expand their share of electricity production, increased electrification of transport, industry, and heating; and a much more rapid uptake of renewable energy in fields beyond the electric power sector.

1.4 Greater attention to clean energy beyond wind and solar PV

For many years, the relatively rapid progress in wind and solar have encouraged policy-makers to focus on developing policies to promote these technologies. Recently, cost and performance improvements in battery technology—in part enabled by market leaders in the electric vehicle space—have enabled energy storage to enter the mainstream in many areas. In 2018 the world now has over 3 million electric vehicles on the road—many in China—and new wind and solar PV projects are starting to integrate battery energy storage.[14] Policymakers have encouraged the pairing of battery energy storage with renewable energy through both subsidies—in markets such as California, New York, and Germany—as well as auction designs that emphasize when electricity will be generated.

In many countries, regulators are grappling with the issue of how to restructure incentives in the power sector to ensure reliable, clean, and inexpensive electricity while coping with high shares of variable renewable energy. The European Union has made progress on developing a closer Energy Union, boosting transmission capacity between countries and most recently raising its renewable energy target to 32% in 2030 and easing rules for approval of distributed energy.[15] In the U.S., individual states such as New York have worked on sweeping reforms of the utility sector, proposing a model where grid and distribution companies see their primary role as facilitating distributed energy, including both generation and storage, rather than delivering power from central plants. It will take time to see how these proposals evolve.

1.5 Businesses are also leading on clean energy

Climate change has gradually begun to affect business and investment strategies and behavior in the private sector, reflecting greater investor and consumer attention to the issue. One of the most important results of the Paris agreement is how it has focused the global business community on climate change. Many global enterprises within the consumer product space, such as retail and electronics firms, want to show customers that their products and supply chains are sustainable. Global financial firms want to show that long-term investments are both consistent with the Paris agreement as well as unlikely to be adversely affected if governments adopt stronger climate policies. The improved cost-competitiveness of renewable energy has also encouraged these shifts, since complying with urgent climate objectives often also makes economic sense for businesses at all levels.

Demand for clean energy from big consumers, such as Apple, Google, and IKEA, often takes the form of power purchase agreements and distributed energy (such as rooftop solar or energy storage). Corporate power purchase agreements for renewable energy amounted to 5.4 GW in 2017, a new record which represented a 27% increase over 2016.[16] RE100, a coalition of companies committed to sourcing 100% of their global electricity consumption from renewable sources, began in 2014 and by August 2018, had 140 companies with 100% renewable commitments.[17]

Companies, especially industry giants, are pushing the development of clean energy from the demand side. The global search giant Google announced in its annual environmental report that it would use 100% renewable energy for all data centres and operation centres by the end of 2017. Similarly, Apple has realized 100% clean energy power in its detail stores, offices, and data centres in 43 countries and regions. IKEA has a goal to produce renewable energy equal to energy consumed by its operation by 2020. IKEA has installed 700,000 solar panels in its stores and buildings around the world. These and other corporate commitments not only represent demand uptake for renewable energy, but also have the potential to lead policy-makers to adopt market designs more amenable to distributed energy and long-term renewable power-purchase agreements.

Investors have become key source of equity finance for renewable energy projects in recent years. Institutions such as pension funds and insurance companies committed an estimated $2.8 billion to European renewable energy projects in 2016, nearly 10 times the total in 2010.[18] Investment shows a trend diverting from coal to renewables. According to data from 350.org, an organisation that campaigns for divestment, more than 700 large investors have committed to cutting their exposure to fossil fuels in recent years.[19] The pension funds of New York, San Francisco, the state of California, and Norway's sovereign wealth fund sent have clear signals to divest from fossil fuels. Two of the largest insurance companies Allianz and AXA announced in 2017 they will stop selling certain types of corporate insurance to coal companies from 2017.

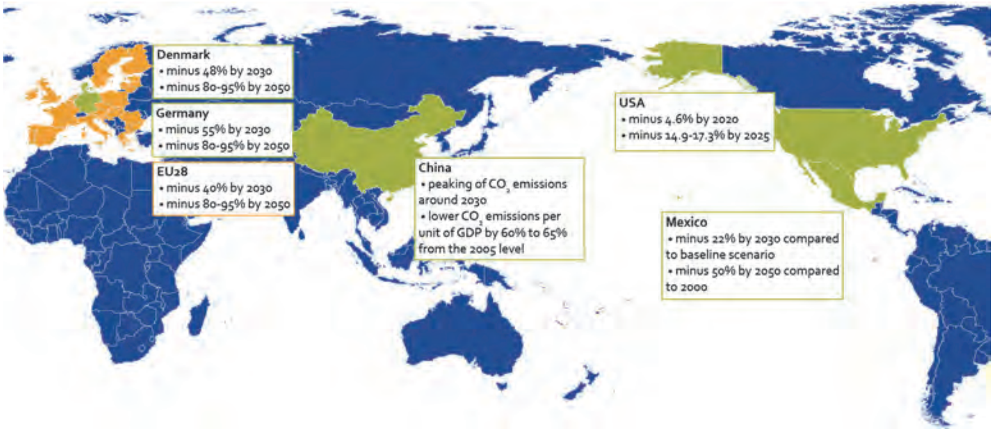
The global energy industry is also preparing for the energy transition. Royal Dutch Shell, the global oil major, has shifted its focus to trading and selling natural gas, renewable power and storage as a strategy for reducing the impact of oil price volatility on operational results. The European electricity industry organisation Eurelectric, representing 3,500 companies in Europe with an aggregate turnover of €200 billion, has agreed on a new vision and strategy, committed to an energy transition with a power sector becoming carbon-neutral well before mid-century.[20] E.ON, the German and European power company, expects a predominantly renewable, much more decentralized, digital and complex future for the energy supply of tomorrow. E.ON is now number three worldwide in offshore wind energy.[21] The Danish energy company Ørsted (former Dong Energy) has published a new business strategy that includes plans to cease using coal in power production in 2023, and focus on clean energy development—mainly offshore wind, where the company now is the world biggest developer.[22]

As this chapter shows, the urgency of meeting climate targets, combined with the increased competitiveness of renewable energy, rising oil price volatility, and increased corporate awareness of renewable energy as a climate and investment strategy are propelling greater action and investment in renewables. The next chapter will illustrate how policy-makers have responded to these trends and challenges in key, indicative regions of Europe (Germany and Denmark), the U.S., and Mexico.

2 Regional trends in energy transition

Global warming affects all countries and can only be tackled in a conjoint international effort, as exemplified by the Paris agreement. In this chapter, we outline progress towards meeting international climate change policy objectives by major countries and regions, focusing in particular on policies that relate to renewable energy: The European Union, Germany, Denmark, the U.S., and Mexico.

Figure 2-1: Overview of key countries' GHG reduction targets, normalized to 1990 levels



All these countries and regions share the need to transform their energy systems from a rather centralised approach with continuous energy generation based on fossil fuels to a more decentralised system with fluctuating energy generation from thousands of energy production facilities. The regions covered have experienced progress in some respects, while in others the countries may have experienced setbacks or stagnating energy transitions.

2.1 European Union

Main drivers for a European energy transition

The European Union (EU) has ambitions to be the leading force in the fight against climate change. It has agreed to spend at least 20% of its budget for 2014-2020 – as much as €180 billion – on climate change-related actions.[23] The EU sees the energy transition as a way to reduce energy imports, which currently account for over 50% of energy consumption, and bolster growth and employment in new industries.[24]

The EU set a long-term goal of reducing GHG emissions by 80-95% by 2050 compared to 1990 levels in October 2009.In October 2014, the European Council agreed to more concrete objectives for 2030, including a decrease in GHG emissions of at least 40 % compared to 1990 levels, and a 27% share of renewable energy along with a 27% improvement in energy efficiency. These targets are discussed in greater detail in last year's CREO.

Current developments – the "Clean Energy for all Europeans" package

Arguably the most far-reaching change in European energy policy will currently come from the "Clean Energy for all Europeans" package, also called the "Winter Package". The Winter Package contains the following elements, among others:[25]

- **Regulation on the governance of the Energy Union:** The EC proposes to introduce a reporting mechanism for all Member States regarding their progress with respect to the EU's energy targets for 2030.
- **Recast of energy market regulation:** The Winter package seeks to reform the Agency for the Cooperation of Energy Regulators (ACER) to create a more powerful agency that oversees the integrated energy market and decides on regulatory issues with cross-border relevance.

- **Energy market reforms:** A new Internal Electricity Market Directive seeks to establish a more market-oriented, consumer-centred and flexible internal energy market, defining consumer rights and the rights of those who produce their own electricity. Several measures are included to empower consumers and prosumers to actively take part in electricity markets.
- **Electricity market reforms:** The reforms include new processes for defining regional electricity markets (bidding zones) to improve cross-border trading, new rules on network access charges that aim to incentivize energy storage and demand response, and new tasks and responsibilities for ENTSO-E and the framework for so-called Regional Operational Centres (ROCs) for increasing the reliability and efficiency of cross-border grid management.

- **Updated renewable energy targets:** The EU will maintain its binding target of at least 27% renewable energy by 2030, while pursuing more detailed measures such as gradually opening the national support schemes for RE to installations located in other Member States, reducing barriers for prosumers to consume their own energy, introducing an annual increase of 1% of RE share in heating and cooling, and gradually increasing the minimum share of sustainable energy in transport from 1.5% in 2021 to 6.8% in 2030.
- **Measures on energy efficiency:** The EU_proposes to increase the 2030 energy efficiency target from 27% reduction of energy consumption by 2030 (compared to 2007 level) to 30%. In addition, the EU will adopt new measures related to building energy efficiency.

The EC's Winter Package proposal is the basis for the ongoing negotiation process between the European Parliament (EP) and the Council of the European Union (representing the governments of the EU Member States). All negotiations and formal approval have to be concluded before May 2019.

2.2 Germany

In 2017, Germany continued to add renewable capacity to the system, leading to a new record in the share of renewables in power consumption. However, its efforts to progress in climate protection have stagnated, and emission reduction and efficiency targets for 2020 are now out of reach. The nuclear phase-out continued with the shut-down of one nuclear power plant.

36.1% of the power consumption was covered by renewables in 2017. With an additional 26.4 TWh of renewable power production compared to the previous year, this marks a new record in Germany. The driving force has been wind power, which now contributes 16.1% of the total power production. Power production from solar power plants has increased, and now contributes 6.1% to the total power production. The usage of biomass for the power sector has lost priority and remains on a constant level of just below 7%.

The current target of the renewable energy law (EEG) for 2025 with 40 to 45% renewables is now within close reach and will be met already in 2020 if the average increase of the share of the past few years continues. The power sector must over-perform in order for Germany to meet the country's 2020 target of 18% renewables in final energy consumption. As the usage of renewable energies for transport and heating is stagnating, the energy sector currently relies on the power sector. The share of renewables in primary energy consumption remained at 13.1% in 2017.

Primary energy and electricity demand increased in 2017 compared to the previous year. Main drivers were economic growth, an increasing population and a comparably cold winter 2016/2017. The primary energy consumption is now back at 2011 levels. Since 2008 it has decreased by 5.9%, which is far from the government's efficiency target for 2020 to reduce the primary energy consumption by 20% compared to 2008.

Even with increasing renewables, the lack in efficiency and the slow utilization of renewables in the transport and heating sector lead to increasing emissions in Germany. Germany's greenhouse gas emissions in 2017 held steady from the previous year: 905 million tons CO_2. While the power sector has shown decreasing emissions—mainly due to the decrease in hard coal-fired power production—these were offset by increases in oil and gas consumption, especially for heating and transport. If the average annual reduction of greenhouse gases since 2000 of about 8 million tons CO_{2e} continues until 2020, Germany would achieve only a 30% emissions reduction in 2020 versus 1990 levels, far less than the target of 40%.[26]

After unexpectedly long negotiations to form a new government following recent elections, the resulting coalition treaty includes new and reformed targets on topics of climate change, energy and transport. The parties agreed to introduce a climate protection law in this legislative period in order to meet the internationally binding 2030 targets. With regard to 2020, the parties agreed to amend the ambitions to meet 2020 greenhouse gas emissions target from a 40% reduction to lowering emissions 'as much as possible, as fast as possible'. This target was changed in large part due to the recognition that the original

40% target would not be reached. The original 2030 target of increasing the share of renewables in gross electricity consumption was increased from 45% to 65%.

A cornerstone for policies regarding the future of coal in Germany is a special commission on growth, structural economic change and employment, bringing stakeholders together to agree on a deadline for the exit of coal and a detailed plan for how to deal with the structural changes this will bring. The Coal Commission is expected to deliver by the end of 2018.

In light of the diesel scandal, the auto industry has come under more intense scrutiny in Germany. Reflecting this, the coalition treaty commits the government to reducing transport sector NO_x emissions. In addition, the coalition treaty states that it will make 'significant advances in electric mobility' with the target of making at least 100,000 new charging points available by 2020.[27]

2.3 Denmark

In 2017, Denmark continued to add renewable capacity to the system, reaching 32.4% of energy consumption covered by renewables. Wind produced 43.8% of power consumption, a new record, while solar now contributes 2.3%. Denmark has therefore already surpassed its EU obligation to produce 30% of final energy consumption with renewables by 2020. Since 1990, carbon emissions related to energy have fallen by 33%, even though final energy consumption has only fallen 1%. The key drivers of this are: increased renewable energy production, and improved efficiency in the energy sector including combined heat and power generation.

Several factors explain Denmark's success. First, there has been broad political consensus about both the goals and the implementation of the most important initiatives. The involvement and stimulation of both the private sector and academia has also been very important for the changes in the Danish energy sector. Long-term policy stability has also been a factor, given that power-sector investments have long investment horizons. For new and immature energy technologies, Denmark has established feed-in premiums and other support mechanisms, while closely monitoring price levels to ensure consumers benefit from price improvements in renewable technologies.

The transition of the Danish energy system has also included smaller consumers and private households, using a combination of energy standards, incentives and public campaigns focusing on energy efficiency, common energy solutions like district heating and changes in everyday behaviour. One of the biggest efficiency gains has been made in the heating of Danish households with an 80% reduction in energy consumption per square meter since the 1960s. Part of the stimulus of energy efficiency has come from introducing energy taxation for businesses and private energy consumers. Raising the price of energy has improved the business case for investing in energy saving technologies and systems.

As an early-mover on renewable energy adoption, Denmark 2020 targets—adopted in 2009—were much higher than the EU average: a 31% GHG reduction goal compared to 1990 levels and 30% of energy from renewables. (Official Danish GHG targets are compared to 2005 levels. Data were converted to 1990 levels based on data available for 1990 and 2005.) Unsurprisingly, Denmark plans to set more ambitious targets for 2030. In 2018, political negotiations on a new Danish energy agreement began to set targets for the period beyond 2020 for the Danish energy sector, with agreement reached as of June 2018. The Danish government now targets renewable energy to provide 55% of gross energy consumption by 2030, which will require substantial new political and regulatory initiatives. This includes adding three 800 MW offshore projects by 2030, and funding of Euro 563m for technology-neutral renewable energy tenders. The government will conduct planning for up to 10 GW of offshore wind capacity in Danish waters to insure further offshore wind capacity can be established quickly if needed.

As part of the new energy agreement, Denmark plans to eliminate coal consumption in the Danish power sector by 2030. This is significant because coal accounted for almost 30% of Danish power generation as recently as 2016. Coal will be replaced by increases in wind and solar power along with biomass and biogas power generation.

Transforming markets has also played a significant role in Denmark's transition. Denmark's power sector has been redesigned to accommodate large quantities of fluctuating renewable power generation, particularly wind power. As described in more detail in China Renewable Energy Outlook 2017, the key elements in the system transition have been advanced planning and forecasting; improving power plant flexibility; creating a capacity power market and an effective and transparent power market; and establishing a strong domestic transmission grid and cross-border interconnectors.

Going forward, with the goal of even more fluctuating power in the Danish energy system, further planning of infrastructure (grid) and market is vital to preserve the high level of system stability and competitive power prices. Further integration and interconnection with neighbouring countries and the EU power system is part of the answer. In addition, the ability to store and use electricity in other sectors like heat through heat converters is being explored. Furthermore, the future electrification of transportation is part of this plan.

2.4 United States

The U.S. has seen a number of developments over the past two years that affect its energy transition. These include policy changes at the federal level eliminating policies related to climate change, state policies enhancing commitments to renewable energy, market reforms related to flexibility and distributed resources, and policy changes that could support energy storage paired with renewable energy.

At the federal level, 2017 saw the Trump administration modify or reconsider many energy-related policies implemented under the Obama administration, including the U.S. Nationally Determined Contribution (NDC) under COP 21, the Clean Power Plan, and Corporate Average Fuel Economy standards for vehicles. In addition to these actions at the national level, state- and local-level actions must also be considered. This is due to the division of authority between the federal government and the states. The federal government has jurisdiction over interstate commerce, whereas the states have primary jurisdiction over local issues such as customer electricity rates and plant siting. In addition to jurisdiction, the impact of federal policy is also mitigated by market factors not regulated by the government, such as the relative prices of natural gas versus coal, and reductions in the cost of wind, solar, and energy storage technologies.

Recent decades have seen a dramatic decline in electricity production from coal. In 2005, coal supplied over 51% of U.S. electricity consumption.[28] Since then, rising supplies of natural gas from hydraulic fracturing and horizontal drilling have led to lower gas prices and build-out of new gas-fired generation. Additionally, renewable energy adoption has increased due to declining wind and solar capital costs and increased investor confidence. Because of these changes, power from coal generation dropped to 30.1% of the U.S. power sector in 2017.[29] At the end of 2017 U.S. coal generation capacity totalled 260 GW, down 17% from 310 GW in 2011.[30] In 2017, renewables accounted for 17.6% of total U.S. electricity generation. Over a rolling 12-month period ending in March 2018, solar generation increased by 39.4% over the previous year, and total renewable generation increased by 11.3%. The transition has also been reflected in jobs.[31] In 2017 in the U.S., some 250,000 individuals were employed by solar firms, and 105,500 by wind generation firms.[32]

State initiatives play an important role in U.S. energy policy. Independent of the federal government, several states and cities have formed a coalition—the U.S. Climate Alliance—to implement the U.S. NDC of economy-wide GHG reductions between 26-28% below 2005 levels by 2025 at the state level. Sixteen states and Puerto Rico are now members of the alliance, comprising 26.1% of 2015 U.S. energy related carbon dioxide emissions.[33] A key policy instrument to achieve this goal has been the Renewable Portfolio Standard (RPS), versions of which have been enacted by 29 states.[34] To date, RPS policies have contributed to 56% of the cumulative deployment of renewables in the U.S. since 2000.[35] Since 2015, 10 states have raised or extended their RPS since 2015, and more states are likely to do so in coming years.[36]

Market reforms are also having an impact on renewable energy utilization. In 2014, California's Independent System Operator (CAISO) established the Western Energy Imbalance Market (EIM) permitting the near-real-time trading of energy between utilities in several Western states since 2014. Mechanisms like this prevent the curtailment of excessive renewable generation by expanding the market's footprint. Eight states and one Canadian province are now part of the EIM, with two utilities having joined in 2018, and three more plans to do so by 2020.[37]

In New York, there have been additional developments in the state's Reforming Energy Vision (NY REV) initiative. Through a series of regulatory changes, NY REV intends to change the role of utilities from selling power at the distribution level to operating a distribution platform for the participation of distributed energy resources (DER). In this vision, the distribution system maintained by the utility becomes a power market for behind-the-meter resources, storage, and microgrids to participate as producers and consumers. The project represents a significant regulatory effort towards a flexible, resilient electric grid.[38]

Many regional markets are shifting away from the concept of baseload electricity, instead emphasizing distributed resources (DR) and system flexibility.[39] California is using DR to reduce the need for thermal plants for peak load. The state's Regional Transmission Organization (RTO) has introduced a Proxy Demand Resource market, which allows for aggregators of DER to participate in real-time and day-ahead energy markets. [40]

Various DER technologies such as PV paired with storage, combined heat and power systems, and microgrids enhance system resilience during system-wide grid outage events. At the federal level, the U.S. Department of Energy proposed a new tariff structure for RTOs to compensate resources which provide resilience benefits, especially those with onsite fuel such as coal and nuclear plants.[41] This proposal was rejected by FERC in early 2018, but FERC has since asked grid operators to provide details concerning how they are planning for grid resilience.[42]

Significant decreases in the cost of battery storage systems have occurred in recent years and continued cost decreases are anticipated. In the future, intermittent renewables could increasingly become paired with battery storage to provide additional grid services in a cost-effective manner. Recent FERC orders could significantly alter the landscape for utility-scale battery storage by requiring grid operators to allow the participation of storage in energy, capacity, and ancillary service markets.[43] Additionally, a recent FERC order requires that all newly interconnected generators provide primary frequency response capabilities. [44] This could result in renewable resources susceptible to deviations in their frequency from wind or clouds increasingly being paired with battery storage to stabilize frequency output.

2.5 Mexico

In recent years Mexico has adopted new policies promoting renewable energy and power sector restructuring, and these have started to show results. These developments are particularly notable in that they show how market reforms are often critical to kick-starting wind and solar, even in countries like Mexico with ample wind and solar resources. Furthermore, Mexico's renewable energy auctions have produced remarkably low bids that have attracted global attention, meaning that more global energy analysts will be looking at Mexico for leads on how developing countries with state-centric electricity sectors can develop wind and solar at low cost.

Currently, Mexico depends heavily on fossil fuels. In 2015, 91% of Mexico's primary energy supply came from fossil fuels. Mexico is the world's 12th largest oil producing country and has also vast unexploited natural gas resources. Oil remains the dominant fuel with demand currently at nearly 100 million tons annually. However, the share of natural gas has increased from 24% in 2000 to 35% in 2015, driven by industrial demand and imports of U.S. shale gas. The share of renewable energy has been relatively stable at around 8-9%.

Sector wise, the transport sector represents the largest share of the energy consumption with nearly 40%. The electricity sector accounts for just 18% of primary energy consumption. Mexico has a total generation capacity of 65 GW, of which 20 GW are non-fossil. Gas-fired power dominates fossil-fired generation. Hydropower (12.5 GW) is currently the largest non-fossil fuel source for electricity, but geothermal energy (0.9 GW) is also an important clean energy source in the country. Mexico has abundant untapped renewable energy sources, but historically the country has seen limited development of geothermal, wind and solar energy. For example, Mexico's solar potential per unit area is roughly the double of Germany, on average, but the country has less than 1 % of Germany's solar capacity.

However, since an energy reform in 2013, polices are increasingly supportive for renewable energy. The energy transition law provides a legal framework for accelerated deployment of electricity from clean energy (CE). CE is defined as renewable sources, nuclear and efficient cogeneration, waste and CCS.

Mexico's energy sector undergoing a period of profound change resulting from a comprehensive energy reform initiated in 2013 as part of a broader economic program. A cornerstone of Mexico's energy reform is the opening of the energy sector to private and international investments to create a more sustainable, efficient, transparent and productive energy sector. Previously, a state-owned fully integrated utility, the Comissión Federal de Electricidad (CFE), was both the sole generator of power since 1992 and also held responsibility for the operation of the national grid. CFE struggled to invest in adequate generation capacity, because electricity tariffs were too low for full cost recovery. Yet Mexico's manufacturing sector suffered from high electricity tariffs. In 2014, 21% of the total costs of electricity supply had to be covered by the general governmental budget.

To resolve these issues, in 2016 Mexico transformed CFE into a State Productive Enterprise (essentially a private entity), along with the oil monopoly Petroleos Mexicanos, or Pemex, a state-owned enterprise operating under private law. These and other reforms have dramatically transformed the governance of the energy sector. In the power sector, responsibilities previously in the domain of state-owned enterprises have been transferred to independent regulatory bodies. In 2015, the Electricity Law established a new regulatory regime for the power sector. The law distributes policy, regulatory and market control to the Ministry of Energy, to a new independent energy regulator regulating the power market, and to a new Independent System Operator responsible for the operation of the transmission grid.

The Electricity Law established a framework for the new power market that will gradually be opened for all types of electricity users. The wholesale market opened to private participation in 2016 with the establishment of a day-ahead market with trading in real time. Power is traded in hourly blocks and prices are set for each node of the transmission grid—the nodal pricing system currently has more than 2,300 nodes. Prices reflect marginal costs of the generators. Bids must reflect operating costs, and regulators are responsible for monitoring the bidding. The independent system operator is responsible for the calculating the prices for each node on an hourly basis.

The Electricity Law also introduced specific targets for clean energy in power generation: 25% by 2018, 30% by 2021, 35% in 2024 and 50% in 2050. The new law introduced a number of products that are traded on a long-term basis: electricity, "clean energy certificates" (CEL) and power generation capacity. By introducing competition for the long-term supply of these products, the Energy Reform seeks to foster private sector investments in CE technologies while minimising the associated costs.

CELs are the principal measure to achieve the CE goal. They are granted to generators for each MWh of power produced from clean energy sources. Furthermore, obligations to purchase CELs are put on very large power consumers. The requirement to hold CELs started in 2018 with a 5 % share, gradually increasing to 30% by 2021 and 35% in 2024. The CELs are tradeable since the beginning of 2018, and serve as a (market determined) subsidy scheme for clean energy. It is an alternative to the use the FiT or FiP commonly used in many countries as subsidy mechanism. The Government sets the targets and the subsidy level is defined by market through trading of certificates. Consumers pay the additional costs for the generator holding CELs. The purchase of capacity is for 20 years and the contracts for CEL's are for 15 years, providing a high degree of certainty to renewable energy investors.

Mexico is using technology neutral auctions to purchase clean energy power generation capacity since 2016. Altogether three auctions have been undertaken so far. During the course of 2017, some of the lowest prices globally for the purchase of energy, particular solar and wind power, were observed. A fourth auction in November 2018 is pending. The auctioned CE corresponds to about 7% of the current demand for electricity in Mexico.

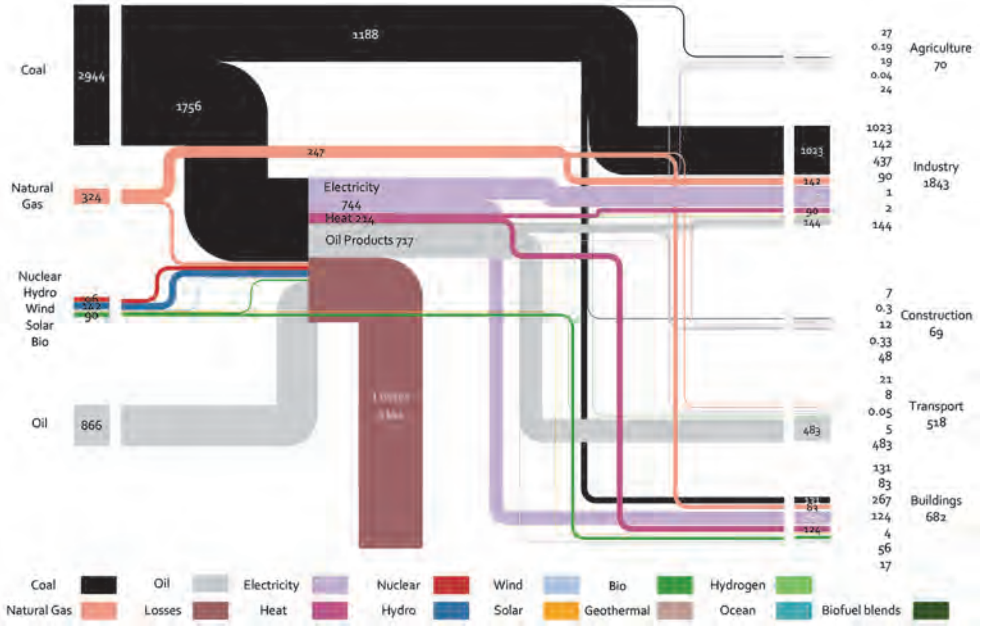
The case of Mexico shows that a rapid and comprehensive turn-around of the energy sector, both in terms of institutions and mechanisms, is achievable with political commitment. Currently, the power market has been only partly implemented and will be fully implemented during the course of 2018—three years since the initiation of reforms. The Mexican experience shows that major changes in the power market can be implemented over relatively short time. Mexico also illustrates how technology-neutral auctions have been successful in driving down costs of new clean generation capacity and attracting qualified investors. Generally, there is potential for Mexico to become even more ambitious regarding clean energy, and the country is likely to meet its clean energy goals more rapidly than anticipated.

3 Status and trends for the Chinese energy transition

China has set the goal of developing in a more environmental friendly and sustainable pattern for the society, called Beautiful China.[45] The transition process includes the concepts of energy system transformation and building an ecological civilization. In the energy sector, the National Energy Administration (NEA) has set the goal of transitioning to a clean, low-carbon, secure and efficient energy system.[46] The government also specifically plans to adjust the energy structure by reducing coal consumption and increasing the use of clean energy.[47] For renewable energy, the transition will require both continuing to increase the scale of renewable additions while also ensuring the scale-up is economically sustainable, consistent with higher-quality growth models.

3.1 Fossil energy development towards more clean

Figure 3-1: 2017 Energy flow chart (Mtce)



Rising energy consumption, and rising clean energy production

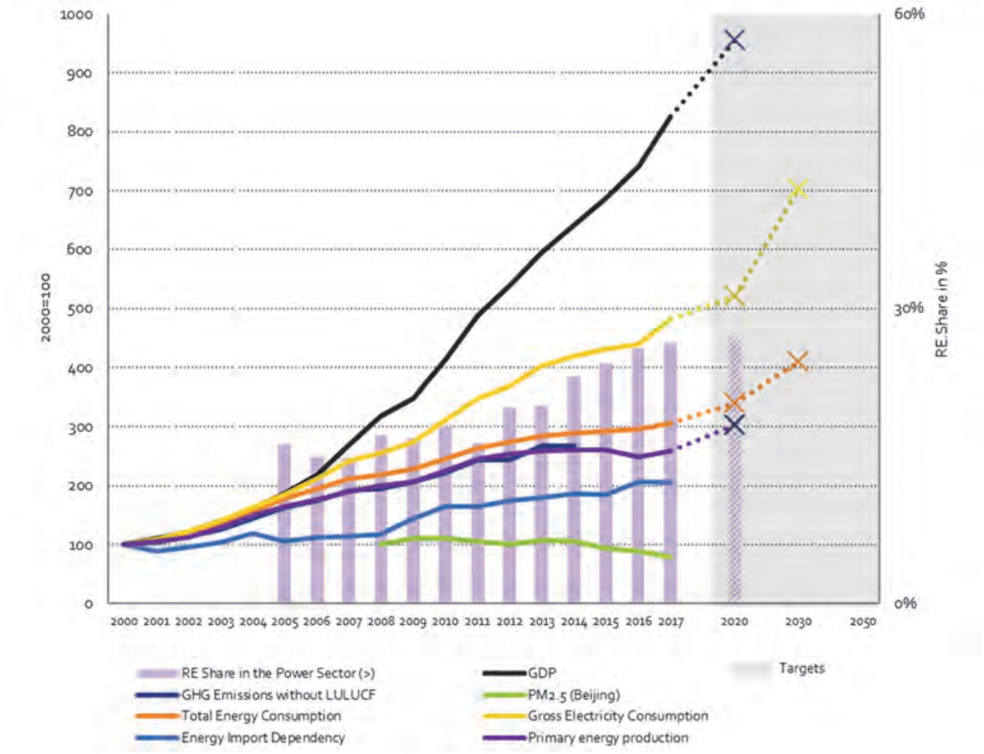
China's transition towards cleaner energy continued in 2017: Renewable energy contributed a larger fraction of energy, but coal and carbon emissions rising due in part to faster economic growth and expanding energy consumption by secondary industry.

Energy consumption: In 2017, China's GDP grew 6.9%, compared to 6.7% in 2016. Energy consumption growth slowed as a result of industrial restructuring and advancements in energy efficiency. In 2017, China consumed 4.5 billion tce (131.9 PJ) of total energy, an increase of 2.9%. Secondary industrial electricity consumption rose 5.5%, tertiary industry power consumption rose over 10%, and household electricity consumption rose 7.8%.

These figures indicate a continuing shift in electricity consumption towards the service and consumption sectors, a key element of China's energy transition.[48]

Energy production: Primary energy production increased by 3.7% compared to -4.2% in 2016. Clean energy production continued to grow strongly, both in absolute amount and in overall share. China produced 6,308 TWh of electricity, an increase of 6.6% from the prior year. Renewable energy supplied 26.4% of electricity produced in 2017. 6.6% of electricity came from wind and solar. Overall, non-fossil occupied about 30.3% of total power consumption. [49]

Figure 3-2: Key Performance Indicators for the Energy System Transition in China [50]



Coal production bouncing back

National coal consumption reached 39 billion tonnes in 2017, it showed a positive annual growth rate for the first time since 2014. This was resulted from stronger economic growth last year. Coal consumption in power, steel and chemical industries increased while building materials and others decreased, but the share of each sector remained stable. [51]

Coal production in 2017 increased for the first time since 2012, reaching 3.52 billion tonnes. Although imports remained below 1% of thermal coal consumption, coking coal imports increased from 59 million tonnes in 2016 to 69 million tonnes, accounting for 18% of total coal consumption. Coal imports rose due to strict policy controls on domestic mining capacity and rising production in the U.S.[52]

Figure 3-3: Coal consumption from 2010 to 2017 53

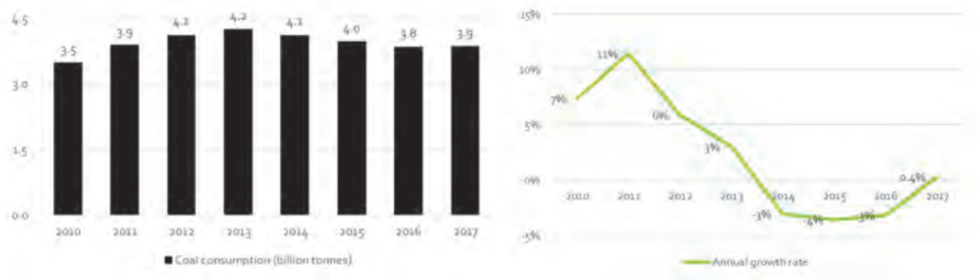


Figure 3-4: Coal consumption by sectors from 2010 to 2017 54

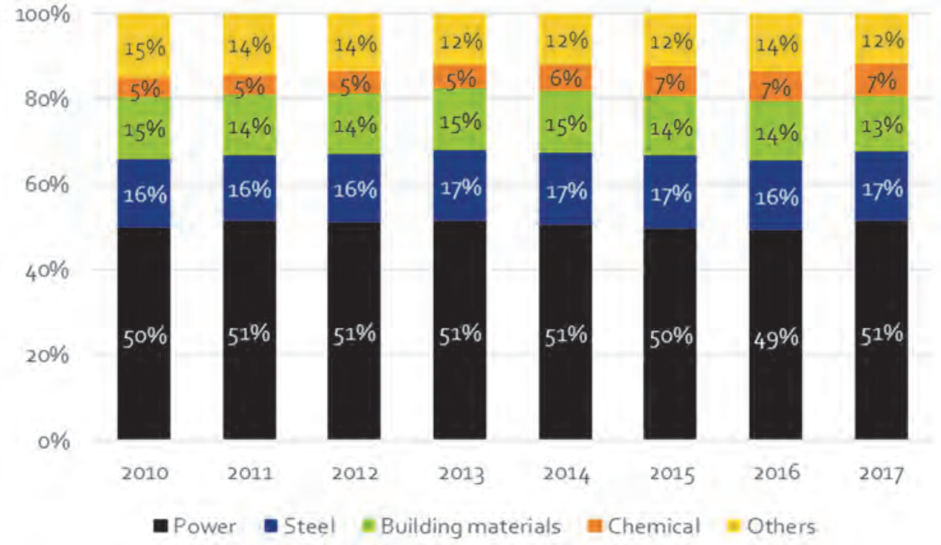
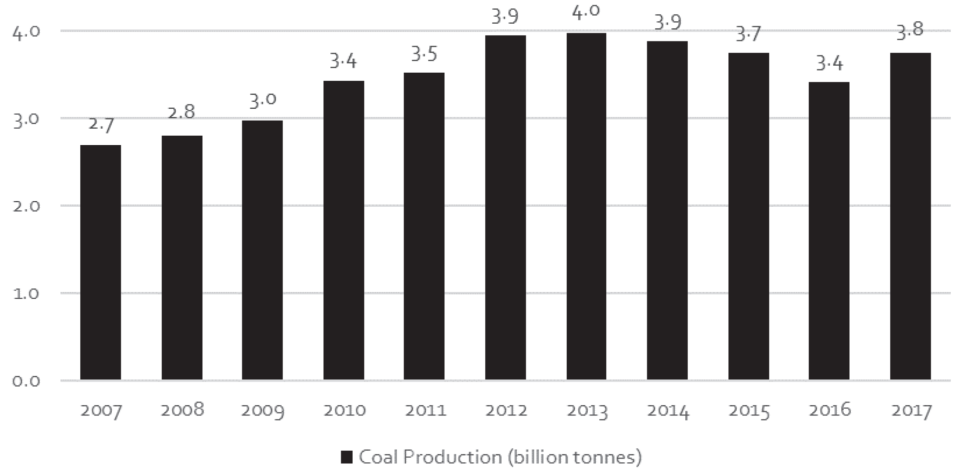


Figure 3-5: Coal production from 2007 to 2017 55



China promoted switching from coal to gas

The 13th Five-Year Plan for energy set ambitious targets for the consumption of natural gas and called for large-scale switching from coal to gas. This transition accelerated in 2017 and should continue apace through 2020. According to the plan, natural gas production capacity in 2020 should reach 220 billion cubic meters and the share of gas in total energy consumption should reach 10%. The proportion of coal in total energy consumption should fall to less than 58%. [56]

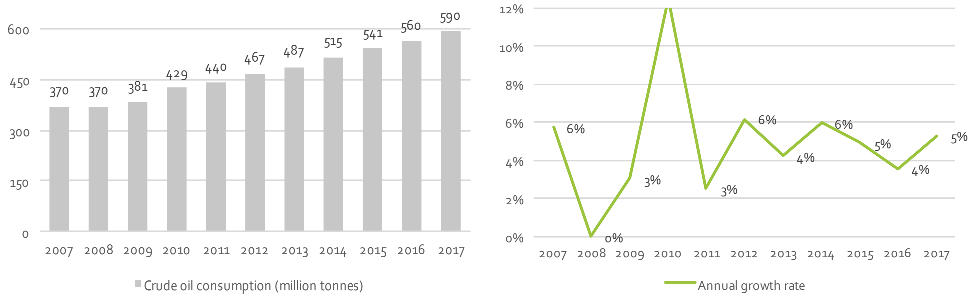
The 13th Five-Year Plan on natural gas development promotes non-industrial demand for natural gas. By 2020, 57% of urban households should have access to gas and the population with access to gas access should reach 470 million. The large-scale effort to switch from coal to gas has focused initially on the Beijing-Tianjin-Hebei (Jing-Jin-Ji) region, the Yangtze River Delta, the Pearl River Delta, and the Northeast China. In these regions, the government promotes switching to gas in urban and rural heating, and in industry. The policy is expected to contribute to an increase gas consumption of 45 billion cubic meters from 2016 to 2020, and eliminated 18,900 tonnes of coal boilers capacity. [57]

In 2017, NEA issued a series of policies in favour of clean energy heating, and the government is accelerating the switching of "coal to electricity" and "coal to gas" in Beijing, Tianjin, and Hebei, where air pollution remains an issue.[58] In May 2017, NEA announced clean heating pilot projects focusing on replacing loose coal (*sanmei*) with clean energy for heating in Beijing, Tianjin, and Hebei. Pilot projects will receive subsidies from the central government.[59] As a result of these programs, natural gas consumption rose 15.3% in 2017, which shows substantial growth contrasted to the 6.6% increase in 2016, and northern areas of China experienced a heating shortage during the winter heating season. The government suspended some gas switching efforts in some areas of Beijing, Tianjin, and Hebei. [60]

China increasingly depends on imported oil and gas

China's oil consumption continues to rise strongly, driven by industrial demand. Total crude oil consumption rose 5.2% in 2017. Industrial oil consumption rose by 5.5%, whereas in the transportation sector, diesel consumption rose 2% compared to decrease in 2016 due to the rapid increasing sales of buses and trucks, while gasoline consumption rose 3% but declined 1.4 percentage points year-on-year. Transportation sector oil demand faces twin pressures of slowing auto sales, and rising shares of transportation via electric vehicles and bikes.[61]

Figure 3-6: Consumption of Crude Oil [62]



Domestic China production of crude oil continued to decline sharply in 2017, reaching 191 million tonnes, down 4.3% from the prior year and 11.0% from peak production in 2015. [63] Multiple factors explain the production declines, including low international oil prices and relatively high cost of domestic production. As a result, oil imports reached 69% of consumption in 2017. [64]

Figure 3-7: Production and Import Dependency of Crude Oil [65]

Domestic gas production rose 8.2% in 2017, reaching 148 billion m^3, supported by national policy. [66] China experienced record gas prices in December 2017 due to an imbalance of supply and demand and a lack of gas storage. Gas imports surged 27% in 2017, and China gas imports reached nearly 40% of consumption. [67] Imports of LNG increased dramatically in 2017, and LNG now occupies 56% of gas imports. [68] China has passed Japan to become the world's second largest LNG importing country after Korea. [69]

Figure 3-8: China Gas Consumption and Import Dependence from 2007 to 2017 [70]

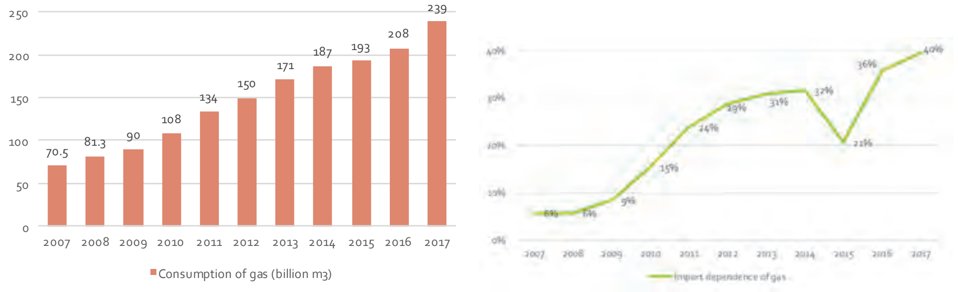
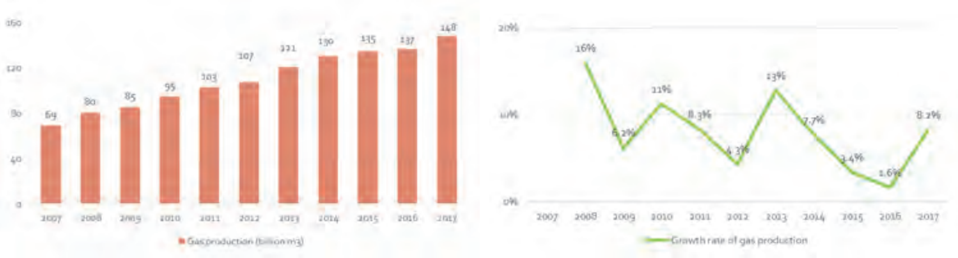


Figure 3-9: Production and Growth Rate of Gas from 2007 to 2017 [71]



3.2 Renewable power keeps expanding

At the end of 2017, China's total installed power generation capacity amounted to 1,777 GW, topping the expectation of 1,700 GW for the year under the 13th Five-Year Plan. Thermal, nuclear, hydro, wind capacity is close to their 2017 targets. Solar PV installed capacity surged 70%, followed by biomass (22.6%), wind (10.7%), gas (8.0%), nuclear (6.5%), coal (3.6%) and hydro (3.5%).

Accompanied with the enhanced capacity in power supply and transmission in 2017, power generation increased significantly and renewable energy showed a significant increase in contribution to power generation. The Eastern and Central China occupied around 76% of the newly installed capacity in 2017, contrasted to 57.9% in 2016, which shows a transfer trend of renewable energy to the eastern and central part of China. National power generation was 6417.1 TW, which increased by 6.5%. Thermal power accounted for 71% of which coal power was 64.7%. Gas power increased by 7.7% and accounted for 3.2% of power generation in 2017. Non-fossil power increased more than 10% and accounted for 30.3% of national power generation. Nuclear power increased to 3.9% of total power generation while the number was 26.4% for renewable power. [72]

Table 3-1: Installed capacity by different sources from 2012 to 2017 [73]

Unit: GW	2012	2013	2014	2015	2016	2017
Total	1147	1258	1379	1525	1651	1777
Share of renewables	28.1%	30.3%	31.6%	33.0%	34.4%	36.6%
Coal	755	796	841	900	946	980
Gas	38	43	57	66	70	76
Oil	6	6	5	4	2	N/A
Other fossil	13	17	20	25	30	N/A
Nuclear	13	15	20	27	34	36
Hydro	249	280	305	320	332	344
Wind	61	77	97	131	147	163
Solar	3	16	25	42	76	129
Biomass	8	9	9	10	12	15
Other renewable	0.2	0.08	0.19	0.09	0.07	N/A

Notice: renewables include hydro, wind, solar and biomass; biomass includes straw, biogas and waste; "other fossil" includes surplus heat, surplus pressure and surplus gas in fossil fuel' other renewable includes geothermal, tidal and marine power in renewable.

Table 3-2: Power Generation by different sources from 2012 to 2017 [74]

Unit: TWh	2012	2013	2014	2015	2016	2017
Total	4987	5372	5680	5740	6023	6417
Share of renewables	19.9%	20.0%	22.7%	24.2%	25.7%	26.4%
Coal	3713	3981	4027	3898	3946	4150
Gas	110	116	133	167	191	205
Oil	6	5	4	4	3	N/A
Other fossil	97	119	139	162	191	N/A
Nuclear	98	112	133	171	213	248
Hydro	856	892	1060	1113	1175	1195
Wind	103	138	160	186	241	303
Solar	4	8	24	39	67	117
Biomass	30	37	44	53	65	79
Other renewable	0.48	0.28	0.54	0.15	0.12	N/A

Notice: renewables include hydro, wind, solar and biomass; biomass includes straw, biogas and waste; "other fossil" includes surplus heat, surplus pressure and surplus gas in fossil fuel' other renewable includes geothermal, tidal and marine power in renewable.

Solar PV capacity has surpassed the 2020 target

For solar, China has already vastly exceeded the 2020 minimum target of 105 GW solar PV power. At the end of 2017, China had a total installed capacity of solar PV of 130 GW, including more than 29.66 GW of distributed solar PV.[75] The increase in solar capacity was due to a solar PV installation rush in 2017 in anticipation of a RMB 0.1 /kWh reduction in the solar PV Feed-in-Tariff (FiT), which takes effect in 2018.

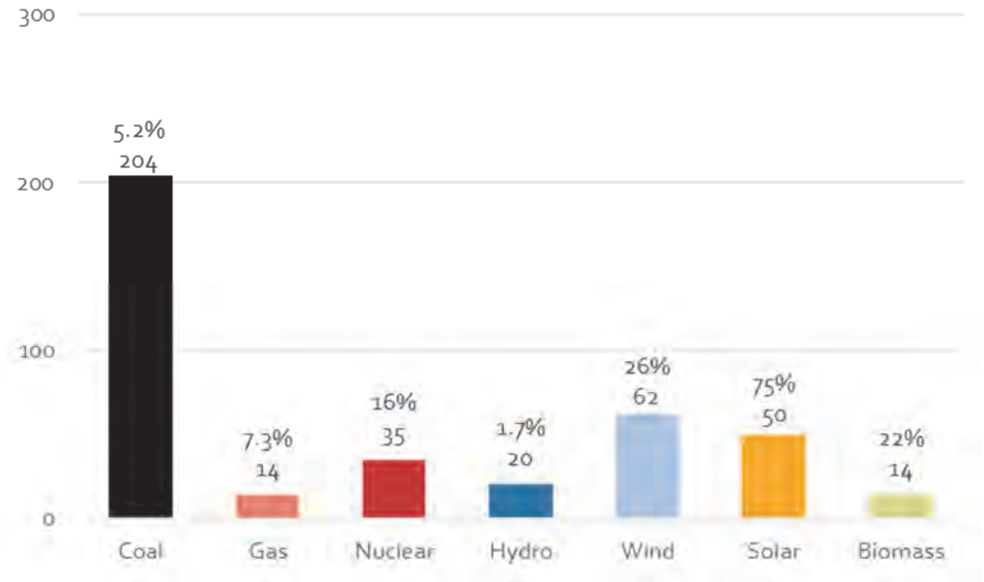
It is notable that wind capacity additions are declining while solar additions are surging: wind additions amounted to 16.4 GW, down from a high of 30 GW two years ago, whereas solar rose by over 53 GW. Wind additions have been slowed by restrictions on new wind in the windiest regions and low FiTs for onshore wind. [76]

For both wind and solar, NEA is increasingly shifting its focus from capacity-based targets to improving planning and integration of renewable energy.

Market rate increased for solar and wind. In 2017, the solar power traded in market amounted to 5.2 GW, and the market rate was 29% for solar. Wind market rate was 28%, which amounted to 138.1 GW. [77] Capital played an important role in solar market. The investment in China's solar industry was 86.5 billion dollars, which increased by 58% compare to 2016.[78] Supportive policy, especially huge amount of subsidy, was also an important positive factor for the growth of solar power. According to the estimate of Ministry of Finance, the subsidy gap for renewable energy has reached RMB 100 billion by the end of 2017. [79] The high subsidy situation was changed in June 2018, with the publication of "Notice on Matters Relevant to Solar Power Generation in 2018", which sent a policy signal to restrict solar power by strictly controlling the scale of new PV projects that could receive subsidy. [80]

Figure 3-10: Wind and solar installed capacity and output in 2017 [81]

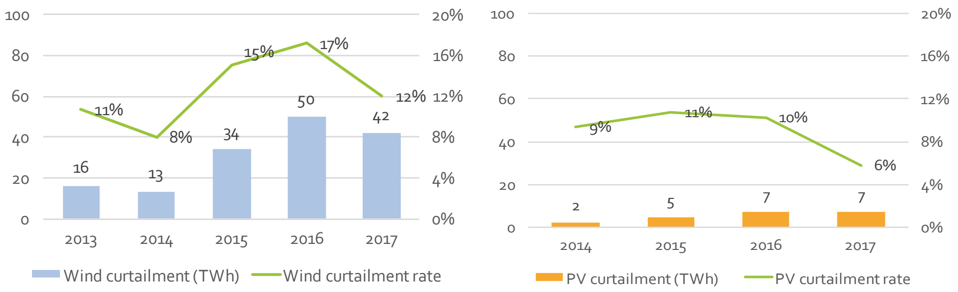
Figure 3-11: 2017 Incremental electricity production by fuel versus 2016 (TWh, and % increases vs 2016) [82]



Wind, solar and hydro curtailment rates showed improvement

Curtailment of wind, solar and hydropower showed signs of improvement in 2017, reflecting both policy and market changes. The average wind curtailment rate in 2017 was 12%, a decrease of 5.2 percentage points from 2016. The solar curtailment rate was 6%, a decrease of 4.3 percentage points. [83] In 2017, the amount of hydropower curtailed in Yunnan and Sichuan fell by 10.4% versus the prior year, reached 42.9 TWh, in which Yunnan fell by 7.9% and Sichuan fell by 15.2%. [84]

Figure 3-12: Historical wind and solar curtailment situation [85]



In 2017, the government adopted a series of measures related to tackle curtailment including restrictions on add wind and solar projects in provinces with high curtailment rate, such as Ningxia, Gansu, Xinjiang, etc., construction of high share renewable Ultra-High Voltage (UHV) transmission lines, increase of renewable bilateral trading volume and promotion of clean heating.

As in prior years, some provinces continued to show severe wind curtailment far above the national average, with Gansu at 33%, Xinjiang at 29%, Jilin at 21%, Inner Mongolia at 15% and Heilongjiang at 14%. Among provinces with curtailment over 10% in 2017, Inner Mongolia, Jilin, Gansu and Xinjiang provinces saw substantial improvements in 2017, whereas other provinces maintained their prior curtailment level. Solar curtailment is still serious in the five provinces in northwest China compared to the rest of China, with Shanxi at 13%, Gansu at 20.8%, Qinghai at 6.2%, Ningxia at 6.4% and Xinjiang at 21.6%. [86]

China's NEA issued investment alerts for both wind and solar, designating areas as red, yellow, or green depending on risk factors such as curtailment and transmission availability. In red areas, unapproved wind power projects should be suspended and construction of approved wind power projects should be deferred. In yellow areas, no wind construction quotas will be given in 2018, except demonstration projects and projects subject to tenders. [87] For PV, the NEA named three provinces as red areas for PV investment; they will no longer be granted PV subsidy quotas apart for projects connected to ultra-high voltage lines. Six yellow provinces received solar PV quotas for 2018, but their subsidy quota will be cut by 50%.[88]

Figure 3-13: (left) Investment alarm for wind power in 2018 [89]; (right) Market environment assessment results for solar power in 2017 [90]

China is shifting towards distributed wind and solar

2017 saw an explosive increase in distributed energy, especially solar. The installation of distributed solar increased by 354.7% in 2017, from 4.26 GW installed in 2016 to 19.37 GW in 2017.[91] The rapid growth of distributed energy in 2017 results from many years of policy development. One new policy relates to the trading of energy from distributed solar, enabling entities to benefit from subsidies while selling a portion of their output to neighbouring businesses. A relatively higher tariff for distributed energy compared to solar feed-in tariffs also pushed solar developers towards distributed solar. Falling solar prices are also helping distributed solar advance in many regions.

Figure 3-14: Newly installed solar PV capacity, 2013 to 2017 [92]

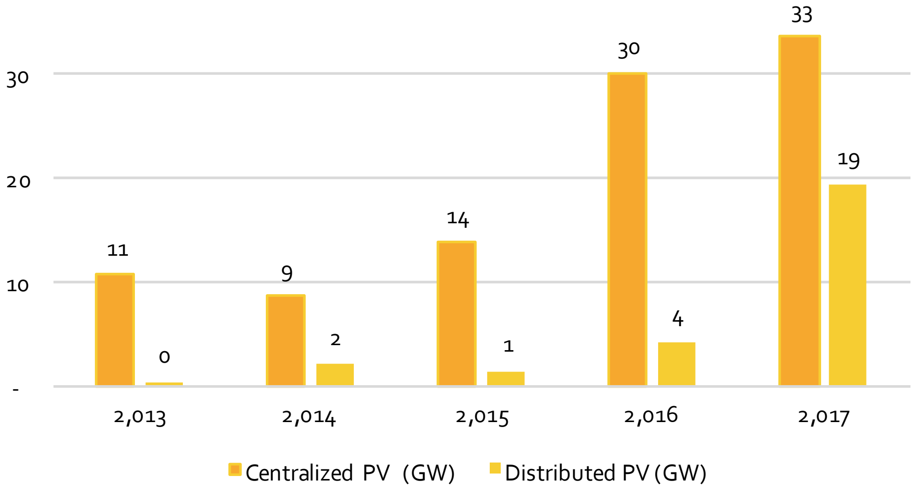
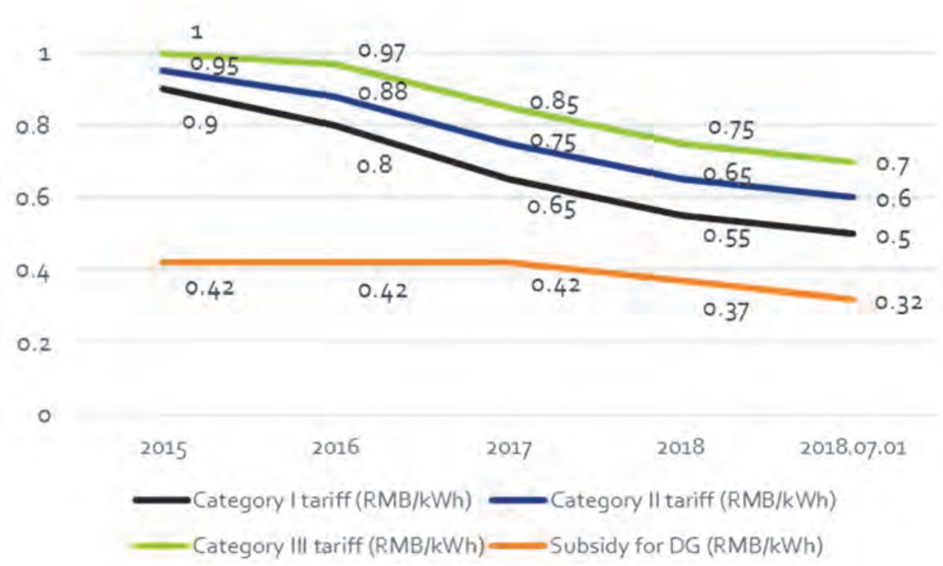


Figure 3-15: Solar PV FiT and distributed PV subsidy policies [93]



Top-runner solar PV becoming price competitive

China's Top-runner program for solar, which began in 2015, is a tender-based program designed to encourage China's solar developers to put more focus on high-efficiency, competitively-priced PV projects. The government grants project winners priority to receive national PV construction quotas, which includes a government-guaranteed subsidy payment.[94]

As the program anticipated, developers have steadily reduced their bidding prices for solar projects. For a Top-runner tender NEA issued in March 2018, a project in Dalate, Inner

Mongolia, offered RMB 0.32/kWh, a new record low and only slightly over the 2017 coal power benchmark feed-in price for Inner Mongolia (RMB 0.28/kWh).[95] Similarly, a Top-runner tender in Baicheng, Jilin, witnessed a bidding price of RMB 0.39/kWh, compared to the local coal power benchmark FiT of RMB 0.3731/kWh.[96]

These prices suggest that solar PV in China's sunniest regions is gradually becoming economical when compared with incumbent coal generation—which benefits from state support in terms of finance, low emissions prices, and other policy support.

Offshore wind, biomass, and geothermal are all growing

Other renewable energy sources show growing but inconsistent trends. The 13th Five-Year Plan for wind power development emphasized offshore wind in the southeast China including Jiangsu, Zhejiang, Fujian and Guangdong. The plan targets 10 GW offshore projects under construction and 5 GW connected to the grid by 2020. In 2017, NEA approved a 13.3 GW offshore wind power developing plan of Fujian. Jiangsu is constructing an offshore project with a total capacity of 800 MW, which for now is the largest offshore wind power project in the world.[97]

NEA and NDRC jointly issued targets for biomass heating in 2017. Biomass heating should supply an area equivalent to 1 billion square meters, while replacing about 30 million tonnes of standard coal annually in 2020. Over 200 counties, 1000 villages and a group of industrial areas should become biomass heating pioneers with an emphasis on developing biomass CHP and biomass boiler heating.[98]

The 13th Five-Year Plan for geothermal energy development, issued January 2017, targets geothermal energy production of 70 million tce in 2020, nearly 30% of which should be in the Beijing-Tianjin-Hebei region.[99] Xiong'an New Area in Hebei, the national-level New Area established by the central government after Shenzhen and Shanghai Pudong, has good geothermal energy potential. In May 2017, Xiong'an began its first geothermal well, which should provide winter heat for 800 households when completed.[100]

Government directs limited funds to promote specific PV projects in 2018

On 31 May 2018, the government announced cuts to solar PV feed-in tariffs for new projects by RMB 0.05/kWh and to cease issuing FiT quotas for utility-scale PV until further notice. The new policy also set a limit of 10 GW for the distributed PV that could receive FiT subsidy, and the subsidy for distributed solar PV will fall by RMB 0.05/kWh to RMB 0.32/kWh. Nevertheless, the new policy excludes poverty alleviation PV projects and Top-Runner PV projects, meaning that the government will direct limited funds to continue supporting such projects that promote specific policy benefits. [101]

As a backdrop of policy release, China's solar PV industry is faced with several problems at the moment, which new policies are intended to correct. The unexpected rapid growth of PV installation seen in 2017 suggested that FiT levels were unnecessarily high, leading to overcapacity in manufacturing and over-building of PV in transmission-constrained areas. Second, the cumulative surcharge deficit reached RMB 112.7 billion in 2017 according to the NEA.[102] Reducing subsidies for utility PV will also impel the solar industry to put more effort on lowering costs. Solar tariff digression is inevitable given the need to reduce fiscal outlays and policy-maker desire to avoid further increases in the renewable surcharge on retail electricity prices.

Table 3-3: new solar PV FiT policy issued on 31 May 2018

Solar PV projects	Feed-in Tariff (RMB/kWh)				Subsidy (RMB/kWh)
	Utility Type I	Utility Type II	Utility Type III	Poverty Alleviation	Distributed*
incl. 2017 quota and connect to grids by 30 June 2018	0.65	0.75	0.85	0.65~0.85	0.37
incl. 2017 quota but connect to grids after 30 June 2018	0.5 (down from 0.55)	0.6 (down from 0.65)	0.7 (down from 0.75)	0.65~0.85	0.32 (down from 0.37)

** Distributed PV that 100% connected to grids will apply utility PV FiT, for self-consumed distributed PV projects, the surplus amount fed into grid apply for the subsidy. Source: NEA.*

3.3 Market reforms in energy sector continue

Green Certificate market has not achieved its goals

China Renewable Energy Engineering Institute launched a market for voluntary green certificates in July 2018. The government has several intentions in establishing the market: reducing subsidy payment, raising public awareness of sustainable development and developing experience for running certificate market, while the policy differed from similar certificates in other countries where certificates are introduced to promote new investment for renewable energy. The certificates were only available for purchase from wind and solar plants already approved to receive subsidies, and there was no secondary trading. The policy did not lead to a rapid uptake of credits by the public, and thus did little to alleviate the subsidy deficit. Companies and individuals purchased only 0.13% of wind certificates available, and only 0.008% of those available for solar nearly a year since the market launched. [103] On many days, no certificates traded hands. Most of certificates were purchased by clean energy manufacturing firms, such as Ming Yang, which makes wind turbines for export. Close attention is now paid to the road map for the marketization of solar power generation. Market for distributed solar is also in layout and pilots with new business models will be constructed. Nevertheless, the non-binding market is expected to continue.

Figure 3-16: Green certificates in market (by June 25, 2018) [104]

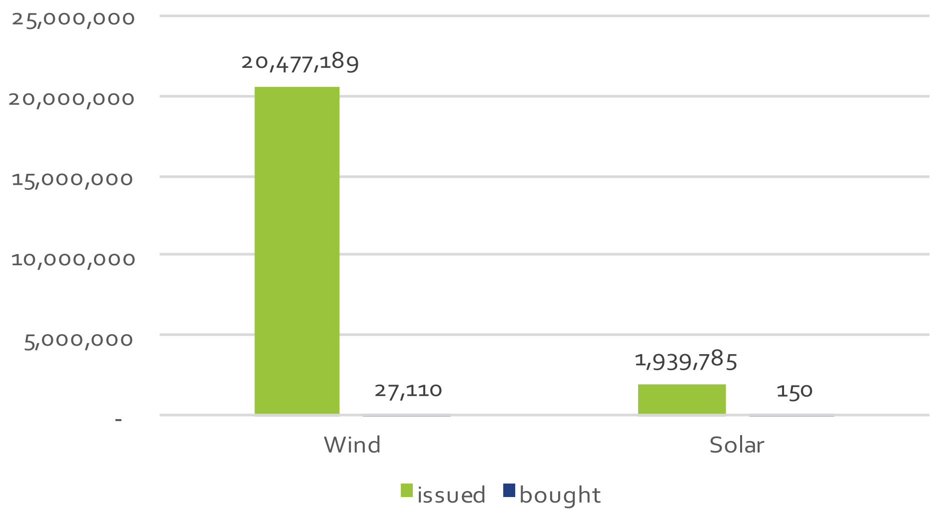
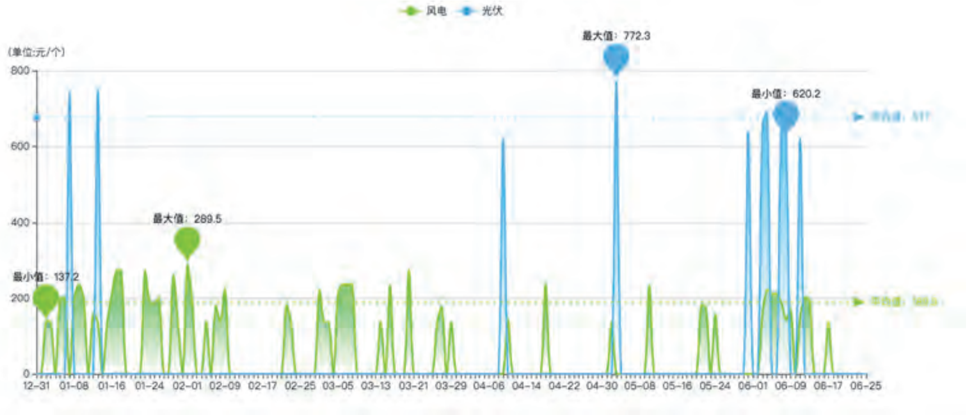


Figure 3-17: The average price level for green certificates [105]



Government releases renewable energy obligation draft

China's draft renewable energy obligation, released in March 2018 and still under intense discussion, is an independent support policy, distinct from green certificates. The government has issued a preliminary plan that would assign certain entities a quota for the percentage of electricity that needs to come from renewable energy. Those entities include provincial grid companies, stated-owned and private distribution grid companies, electricity retail companies, industrial enterprises owning their own power plants, and large end-users participating in bilateral electricity trading. The policy could yet undergo major changes and is not anticipated before the end of the year.[106]

In the long-term, renewable obligations could help promote exchange of renewable energy between provinces. Many of the provinces that will see the largest increase in renewable energy share in total energy consumption are located in East China. Although the present quotas are given in the notice, a binding final policy has yet to be issued.

National carbon market launched but lack of policy framework

In late 2017, China officially launched the process of developing a nationwide carbon market, which will initially apply to the power and heat sector. The national market continues the process begun earlier, under seven provincial carbon trading pilots covering around 30% of China's total emissions. By May 2018, cumulative trading volume amounted to 230 million tonnes CO_2e and the trading value was RMB 5.156 billion. [107]

Carbon markets—under which regulators issue carbon emission quotas to emitting entities, which cannot exceed limits unless they obtain credits from others in the market—are an important tool for governments to mitigate greenhouse gas emission and realize energy transition. Experience in Europe and others suggest that policymakers face obstacles when trying to ensure carbon markets work well with other clean energy and energy efficiency measures. A well-functioning trading system should help narrow the price gap between renewable and non-renewable power, reduce emissions more than would happen otherwise, and incentivize investment in clean energy and efficiency. To achieve this, the government will need to improve long-term energy and emissions policy transparency. China may also need to consider a price floor or automatic adjustment mechanism similar to the Stability Reserve Mechanism to ensure renewable policy and carbon policy work well to reduce power sector emissions overall, rather than only optimizing coal power sector operation.

Figure 3-18: Timeline of provincial carbon market pilots and national market

2013-2014
NDRC established seven carbon trading pilots with the purpose of promoting market mechanisms to achieve by 2020 China's goal of controlling greenhouse gas at a low cost.

2015
After one full year of compliance, Shenzhen and Shanghai have reported 100% compliance, with Tianjin, Beijing and Guangdong reporting compliance rates ranging from 96.5 to 98.9%.

2017
NDRC published the Construction Plan of National Carbon Emission Trading Market that will proceed in three phases

2018
Foundation construction;
By now：
Submission and verification of historical carbon emission, local emission monitoring plans, mechanisms including quota allocation, baselines, and risk management of price adjustments, large-scale training.

2019
One-year trial operation of allowance trading in the power generation industry.

2020
Regular trading of national carbon market may begin in 2020.

Figure 3-19: (left) Trading volume and value of primary and secondary market in pilots by June 201; (right) Trading volume of CCER in pilots by April 2018 [108]

T&D pricing reform and power market pilots underway

Since 2000 China has undertaken two rounds of institutional reforms in the power sector. In the first-round reform, in 2003, the vertically integrated power industry was unbundled. Production was separated and five power generation corporates were established to stimulate the competition. On 25 November 2015, China's State Council issued the Notice on Deepening Power Market Reform, often called Document #9, kicking off the second round of reforms. [109] This reform is expected to see the further deregulation and liberalization of power transmission, distribution, and retailing.

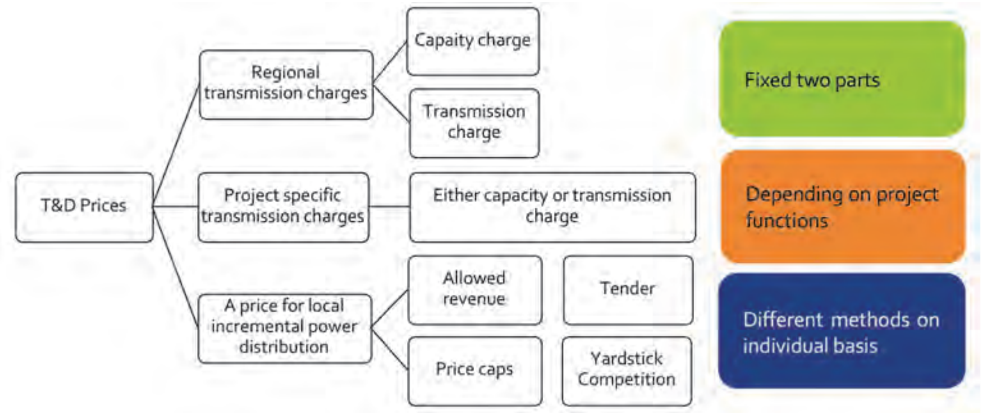
Following the release of Document #9, the government issued six supporting policies that (1) establish spot power market, (2) build electricity trading exchanges and run normatively, (3) open up electricity retail markets, (4) reform prices for transmission and distribution (T&D), (5) power retailing side reform, and (6) regulate so-called captive coal power plants used by industry. [110] In connection to these reforms, NEA has launched pilots for improving the flexibility of coal-fired power plants, which is essential for integrating the variable production of wind and solar electricity.

T&D price reform's initial phase completed

According to the government's overall plan for power markets, reform of transmission and distribution (T&D) prices is the first and pivotal step. T&D pricing reform aims to change the grid company business model, shifting grid revenue towards providing T&D services instead of selling electricity. The service price is determined by T&D costs (estimated by government regulators) plus reasonable profit. Ultimately, the reform aims to establish a reasonable, stable and clear T&D price system.

T&D price reforms have been implemented across China in 2017, marking T&D pricing reform as the first of the six reforms to be implemented nationally. The government established a systematic framework for regulating and monitoring T&D prices. [111] T&D prices consist of three categories: regional power transmission charges, project-specific power transmission charges, and a price for local incremental power distribution. Pricing for inter-regional and inter-provincial major power transmission and interconnection projects—such as the West-to-East project, the Xinjiang power export project—will be determined case by case.

Figure 3-20: A brief summary of T&D prices mechanism



Minimum purchase of coal power decreased year by year

In tandem with the new T&D price system, the government has started to replace the previous system of planned power plant operating hours with reforms that place greater emphasis on integrating energy security, energy supply-demand balance, renewable integration, and emission reduction.

According to the *Opening Power Generation and Consumption Plan* of NDRC, the amount of electricity output of each coal-fired power plant subject to guaranteed operating hours by grid companies in the current year shall not exceed 80% of the prior year. Coal-fired generation units approved after Document #9 will not receive any guaranteed hours, and should be dispatched only according to direct, monthly and annual bilateral purchase contracts. [112]

As this suggests, bilateral trading between generators and retailers is a major element of this market reform. Currently, industrial and commercial (C&I) consumers connected to 110-kV or above lines can engage in direct power purchase agreements—generally of monthly or one-year duration. More retail market participants will join in the future.[113] In this case, consumers will no longer pay as the catalogue tariff, however some subsidy and priority are still maintained at this stage. For example, the 'cross-subsidy' will continue reducing the tariff for residents in remote rural area with the revenue from C&I consumers, although the transmission cost for them is significantly higher than for C&I consumers. Nevertheless, the subsidy is expected to decline and ultimately free from market.

Developing bilateral markets may help transition China towards a wholesale electricity market, but many further steps are needed to achieve this objective, as well as to completing China's ambition to promote renewable integration through wholesale markets.

Ancillary service pilots are expanding

Ancillary services markets are an essential towards disaggregating various grid services from a centralized system based on thermal power, opening the market to new participants, and boosting the flexibility of the entire power system to enable renewable energy. Historically, only coal power plants provided ancillary services, and the system was designed to pool these costs among thermal generators, giving little incentive for flexible operation or renewable integration. Under new ancillary services pilots, this is gradually changing.

Thus far, China has launched ancillary service market pilots in regions planning to launch spot power markets. Ancillary services in China are divided into capacity reserves, frequency regulation, voltage regulation, and automatic generation control (AGC). Since January 2017, the government has established ancillary service market in three-north regions and southern China. The function of different markets caters to disparate local energy deployment situations. In Guangdong province, which had a long-running shortfall of frequency regulation, the ancillary service market began with frequency regulation services. Gansu and Qinghai provinces, which suffer high wind and solar curtailment, have set up capacity reserve markets with the goal of increasing renewable consumption.[114]

These provincial ancillary service market pilots have shown promising results, but more work is needed to ensure ancillary service markets are open to all participants, with transparent rules set far enough in advance to enable cost-effective investments and wide participation.

Several provinces are taking the lead in spot market pilots

Without a spot power market, coal power is still cheaper than government-set tariffs for wind and solar, and transmission system operating practices make it difficult for wind and solar to find buyers across provincial boundaries. Currently, provincial governments and grid companies have incentives to promote utilization of within-province generation, which also acts against purchase of renewable energy from other provinces. For these reasons, the government plans to establish a national spot power market in the next phase of power market reform.[115] Spot market prerequisites include reliable infrastructure, ancillary services markets, and T&D price reform—all of which are now underway in some.

NDRC and NEA announced a first batch of spot power market pilots in August 2017. These pilots covered eight regions including Southern China (starting with Guangdong), Western Inner Mongolia, Zhejiang, Shanxi, Shandong, Fujian, Sichuan and Gansu. The policy aimed to complete the pilot designs by the end of 2018.[116]

Figure 3-21: The first eight spot market pilots in China

Among all the pilot provinces, Jiangsu and Zhejiang provinces have taken the lead. Both two provinces have well-connected regional high-voltage grids (500kV backbone transmission network), variety of generation capacities and well-established power exchange platforms. In September 2017, Zhejiang arranged the first tender in China for the provincial spot market construction with RMB 40 million. China Electric Power Research Institute partnered with U.S. independent system operator PJM, won the bid to design a power pool system for remunerating generation.[117]In the same month, Zhejiang and Jiangsu consecutively published their roadmaps for establishing the power spot market.[118] Zhejiang spot market is expected to operate at the first half year of 2019 with detailed action plans arranged.[119]

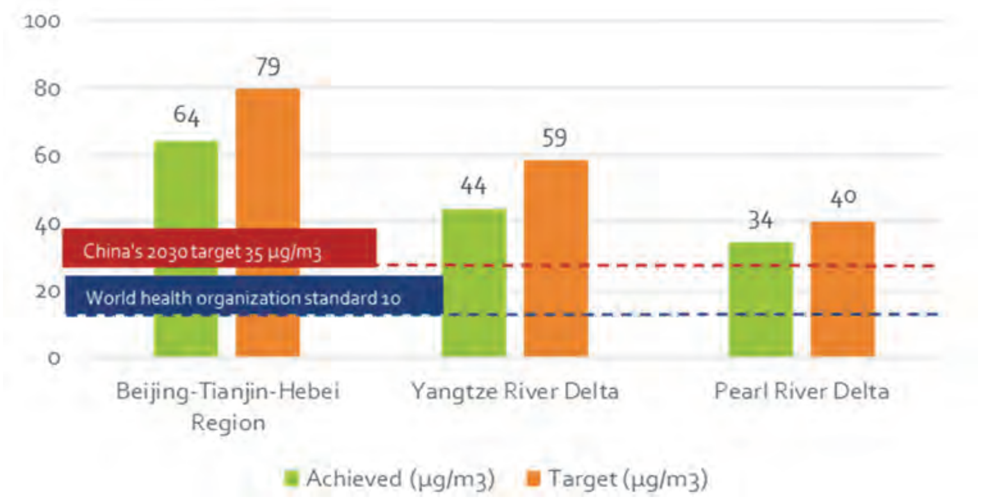
For achieving the energy transition in a large capacity as China, reforms are in need in all sectors but not restricted to the power system. The management of energy-intensive industry acts as a significant role in carbon reduction and efficiency improvement.

Figure 3-22: Overall development roadmap of Zhejiang pilot spot power market

3.4 China has made notable progress in cracking down air pollution

The major five-year (2013-2017) air pollution control targets were all achieved by 2017. The overall air quality and number of blue-sky days were improved greatly. [120] However, PM2,5 level in China is still higher than WHO suggested level of 10 µg/m³. After the triumph in 2017, the State Council put forward the Three-year Action Plan to Protect Blue Sky to continue efforts to improve air quality. [121] The plan focuses on total amount of emissions rather than on emissions intensity in previous policies—a stricter metric that represents stronger resolve. The plan further lays out specific pathway toward the goal. In addition to targets for concentration of pollutants, the plan also includes specific technology standards and requirements. Target industries cover power sector, industries, vehicles and fuel. The plan will phase out in-efficient or distributional coal-fired equipment. As for renewable energy, the plan states that wind, solar, and hydro curtailment should be "basically resolved" by 2020.

Figure 3-23: Achievements of PM 2.5 for the 2013-2017 air quality control plan [122]



3.5 Future trends and key topics for the future transition process

It's hard for renewable to replace existing coal

Coal consumption in 2017 increased by 0.4%, the first year of growth since 2013. Coal still plays the dominant role in China's energy sector. Though renewable energy has grown rapidly, it is difficult to see existing coal substituted by renewable energy in primary energy consumption.

Electricity consumption has grown rapidly in the past few years: 5.0% in 2016, 6.6% in 2017 and 9.4% in the first half of 2018. [123] The coupling of economic growth and electricity consumption growth is a crucial factor in determining whether and how quickly the energy sector can decarbonize. Given policies promoting electrification of industry, heating, and transport, and the recent economic recovery, rapid growth in electricity consumption is expected to continue. Ideally, China should focus efforts on ensuring renewable energy meets a larger and larger share of incremental electricity consumption growth.

Renewable energy additions must continue to grow

The overall policy environment of renewable energy remains unchanged: The government's vison is to establish an energy system that is green, efficient, low-carbon and clean. Policies are also focused on achieving the national carbon emission target of reducing carbon emissions per unit GDP by 40% to 45% by 2020 and 60% to 65% by 2030, compared to 2005 levels.[124] In terms of renewable energy policy priorities, the focus is shifting from overcoming technical bottlenecks to establishing an economically-sustainable market environment for clean energy. Given the cost reductions experienced by renewable energy, the government has gradually and inexorably adjusted incentive policies. The biggest problem currently is to overcome wind and solar curtailment and to phase out feed-in tariffs. At the beginning of 2018, the government adjusted several aspects of renewable subsidies including annual construction quotas for projects receiving subsidies, subsidizing methods, and subsidy price levels. In addition, the government is shifting towards auctions for new wind power projects. Policy fully supports wind and solar projects that already achieved price parity compared to present prices for power derived from coal (which, as noted elsewhere in this report, presently inadequately account for carbon prices or other externalities). Because wind and solar are becoming more competitive, subsidy and quota adjustments do not necessarily mean renewable energy additions will plunge.

Reducing wind and solar curtailment rates is also an important aspect of reducing the cost of renewable energy. The solution of this issue include two aspects: policy-level and technological measures. Specific measures include breaking down provincial fortresses (provincial protectionism) for power trading, raising demand through renewable obligations, as well as increasing utilization of existing inter-provincial transmission grids. In addition, the reduction of non-technical cost is also a key for the healthy development of the industry. This includes reducing land cost for renewable energy and reducing project approval times. Reducing these so-called "soft-costs" is especially important to the development of distributed renewable energy, and will require the attention of a variety of government departments.

Part 2:
China Energy System Outlook

4 Scenarios for the future energy system

Building a clean, low-carbon, safe and efficient energy system is a complex and challenging task, involving many different policy measures, which directly or indirectly influence each other. In CREO 2018, Part 2, we set-up the scientific and quantitative platform for the policy decisions by analysing two different scenarios for the future energy transition. In chapter 4 the boundaries and methodological approach are described. Chapter 5 gives the overview of the whole energy system development towards 2050, while chapter 6, 7, 8 and 9 gives the outlook for the end-use sector, the power sector, renewable energy and storage technologies.

The outlook for renewable energy in China builds upon comprehensive analyses of the Chinese energy system in form of two detailed, bottom-up scenarios for the development towards 2050: The Stated Policies scenario and the Below 2 °C scenario.

The scenarios are based on scenario *boundaries*, scenario *assumptions* and scenario *strategy*.

4.1 Scenario boundaries

The boundaries for the long-term energy and economic development are constraints to the deployment of various energy technologies:

- The development of nuclear power plants is limited by the Chinese government's decision to promote nuclear plants only in coastal areas for safety reasons. Based on an assessment of the potential sites in along the coast, the maximum nuclear capacity is limited to 120 GW.
- The development of hydro power plants is limited by existing reservoir capacity and environmental constraints for establishing new hydro plants and reservoirs. The long-term maximum capacity is limited to 532 GW.
- The different renewable energy resources face resource constraints on a provincial level. Wind and solar resources are divided into categories with different resource quality, depending on wind speed and solar radiation.

4.2 Scenario assumptions

The scenarios are based on the following main assumptions:

Economic development will remain a precondition for reaching China's socioeconomic goals for 2050. This entails growing GDP by a factor of 4 in real terms, from RMB 82 trillion in 2017 to RMB 324 trillion by 2050. Population is expected to be on today's level at 1.38 billion; thus annual per capital GDP would reach RMB 235,000 (based on 2017 price levels). However, this reflects not only a continuation of prior growth rates but also a genuine transformation of the economy and energy systems to a green and low-carbon model of economic development.

The short-term goals in the 13th Five-Year Plan on energy will be fulfilled in 2020, as well as the targets in the Three-Year Action Blue Sky Protection Plan, the 13th Five Year Plan for Environment Protection and the North China Clean heating plan.

For natural gas, the model includes the assumption that China reaches its goal of 10% of natural gas in total primary energy consumption. For the Stated Policies scenario, the model assumes that natural gas consumption will further increase to cover 15% of total consumption, while the Below 2 °C scenario omits all minimum requirements for natural gas after 2020.

The Stated Policies scenario is based on China's current target for a carbon intensity reduction of 40-45% by 2020 and 60-65% by 2030. While these targets are for the entire Chinese economy, we apply the same reduction to the energy system. The scenario modelling shows that these targets are not binding constraints on the energy system development due to other drivers. For the Below 2°C scenario, we base carbon constraints for the energy system on several different simulations from the IPCC AR5 database with a greater than 66% chance of staying Below 2°C warming.

4.3 Scenario strategy

The strategy for the scenarios is based on the *overall energy strategy* for China.

Stated Policies scenario: Impact of strong implementation of current and planned policy

The Stated Policies scenario uses key policy documents in the short-term as implementation strategy. The current policy trends are extrapolated to set the longer-term policy drivers. This includes the official climate target to reach "the carbon emission peak by 2030 and to strive to achieve it earlier."

Below 2 °C scenario: How China can build an energy system for the ecological civilisation

In the Below 2 °C scenario, China vigorously implements an ambitious vision for an ecological civilisation. The Below 2 °C scenario shows how China can contribute to the fulfilment of the Paris agreement by setting a hard target on CO_2-emissions.

An energy system vision for a Beautiful China

In 2050, the Chinese energy system should comply with all overall quality criteria reflected in the 13th Five-Year Plan and in the visions for an ecological civilisation:

- A clean energy system does not pollute the air, water or soil due to activities in the whole energy supply chain from mining to disposal of waste. This implies a drastic reduction of coal use outside of the power sector, less coal-mining, and efficient use of flue gas cleaning for the remaining coal-use in the power sector. Coal is constrained to 1 billion tons by 2050.
- A low-carbon energy system requires a general transition away from fossil fuels towards non-fossil fuels. Even though coal has the highest CO_2 content per unit of energy, oil and natural gas should also be restricted in a low-carbon energy system.

China's overall energy strategy

After the Peoples Party Congress in October 2017, China's future energy strategy has become clearer and more focused. The central policy objectives are now to complete the development of a *moderately prosperous society* by 2020; to achieve *basic modernisation* by 2035 and build a *great and modern country* which is *prosperous, strong, democratic advanced, harmonious and beautiful* by 2050. Strong emphasis is placed on the transition of the development of the economy *from High Speed to High Quality*, a paradigm shift which shall also be adhered to in the energy sector. With the important milestones for 2020, 2035 and 2050, it is the policy of China to develop a "clean, low carbon, safe and efficient energy system."

The concept of an *ecological civilisation* is central to this development ensuring that economic growth will not happen at the cost of the environment, people's health and livelihoods. In the coming years, the energy agenda in China has the following priority areas, according to NEA's 2018 work guidelines:

- More attention to green and low-carbon development
- More attention to improving the quality of the energy supply
- More emphasis on improving energy system efficiency
- More emphasis on innovation-driven development
- More attention to safeguarding and improving people's livelihood
- More emphasis on openness and international cooperation
- More focus on energy governance and the rule of law.

The specific activities include further progress on *power market reform*, strong measures to reduce the *overcapacity of coal mining and coal power production* and thereby *reduce the consumption of coal*, fundamental changes in the *RE subsidy schemes*, a more coordinated *development and use of the power transmission grid*, improving the *flexibility of the power system*, including power plant flexibility, strong focus on *energy efficiency measures and green consumption*, and developing a consistent and *long-term energy strategy planning*, aiming to set milestones and new roadmaps for development towards 2035 and 2050.

- A safe energy system is a reliable system, and has limited dependence on fuel imports. It follows that China's oil and natural gas consumption will be limited due to domestic resource constraints.
- An efficient energy system is efficient in the use of energy, meaning that useful energy is not wasted, transformation losses are low, and energy efficiency in the end-use sectors is high. It also is a cost-efficient energy system, where the dispatch of the power system is based on least-cost optimisation, thereby minimising the total cost for the whole system. Furthermore, planning and investment in new power generation and other energy infrastructure, creates a cost-effective portfolio of assets working together to reduce overall costs. China has chosen to use the market forces as a

decisive part of the economic transition, and increasing the role of markets in the energy system specifically.

These characteristics help paint a clear picture of China's 2050 energy system:

- China's dependence on fossil fuels, particularly coal, falls dramatically, replaced by non-fossil fuels in all sectors.
- China implements rigorous energy efficiency measures in end-use sectors. This includes eliminating thermal power plants and their attendant conversion losses with low-loss wind and solar energy, as well as electrifying end-use consumption, primarily the industry and transport sectors. Deployment of distributed energy further reduces overall system losses.
- By adopting efficient power markets and pricing carbon emissions and other pollutants to reflect direct and indirect costs, China improves the overall economic efficiency of its energy system.

4.4 Bottom-up model analyses

The scenarios are represented in CNREC's energy system modelling tool, consisting of three interlinked models: EDO, END-USE, and CGE. The EDO (Electricity and District-heating Optimisation) model is a fundamental model of power and district heating systems on a provincial level. 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. The models are linked, such that EDO calculates the generation mix to satisfy the demand for power and district heating, while other transformation sectors are handled in LEAP. The CGE-model (Computable General Equilibrium) uses the results from the EDO and END-USE models to estimate the macro-economic and structural impact of the energy system transformation, including job-creation and destruction.

5 Energy system outlook

This chapter reviews the results from the scenario analyses from an energy system perspective. Subsequent chapters describe the end-use sectors and the power sector in more detail, as well as analyses of the macroeconomic impacts of the scenarios. These are followed by a renewable energy technology outlook.

5.1 Fossil fuels dominate the current energy system

China developed its current energy system to enable the country's historic rapid economic growth. During the 40 years since the beginning of the Reform and Opening era, China's GDP has increased 35 times, and its primary energy consumption grew from 570 Mtce to 4490 Mtce between 1978 and 2017. China's energy intensity per GDP is now 1.8 times that of OECD Europe.

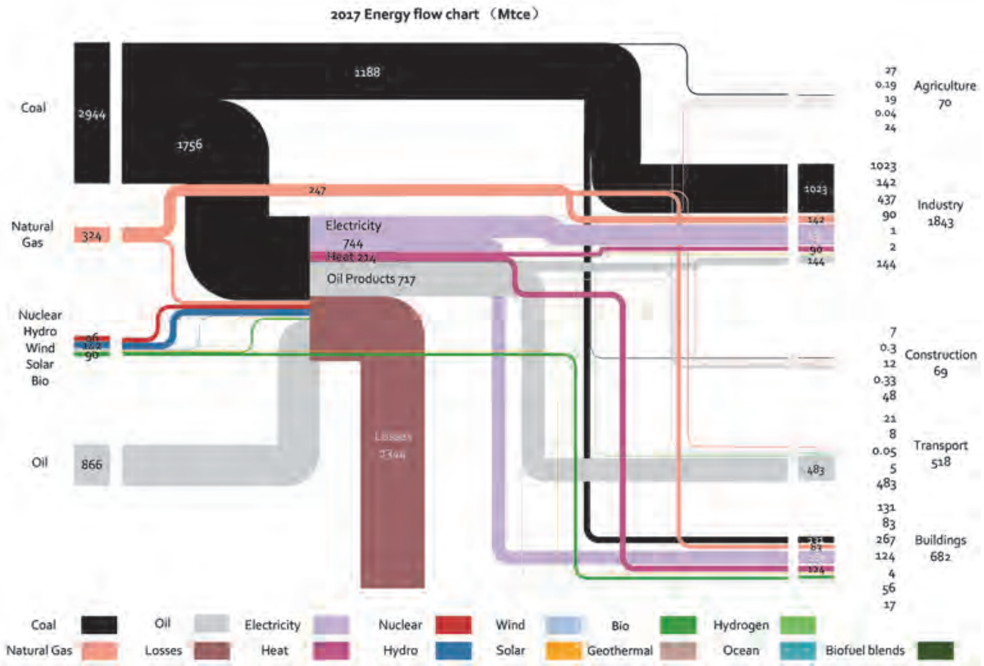
Industry accounts for more than 60% of final energy consumption in China today. Four energy-intensive industries—steel, chemicals, non-metallic, and nonferrous metals—account for more than 75% of industrial energy demand. The transport sector accounts for 16%, yet consumes 67% of oil products and therefore holds the main responsibility for China's high oil import dependence. The building sector accounts for 21%, a relatively small share compared to that of European and North American countries.

A note on energy data

The data for reference year is mainly collected from China Energy Statistical Yearbook. It is however notable that China's energy statistics is collected primarily from large industrial enterprise with the annual income exceeding $20 million or comprehensively energy consumption over 10,000 tce. Hence, a small part of actual energy consumption is not listed in the national statistics, mainly heat consumption. Due to the lack of a metering system, China's heat consumption cannot be counted like electricity or gas. Only industrial plants or large central heating companies are qualified to be included in this national energy statistics, resulting in an underestimation in residential heat demand. Likewise, fuel consumption for such heat demand is neither included.

In this study, CREO takes the data from MOHURD's < China Urban-Rural Construction Statistical Yearbook > and CEC 's < China Electric Power Yearbook > as supplements, adding about 80 Mtce heat consumption into final energy consumption and around 200 Mtce fuel consumption in the in the primary energy consumption, and conducts the wholistic modelling based on these corrected national data.

Figure 5-1: Energy flow chart for the Chinese energy system in 2017



China's primary energy consumption is dominated by coal (64.4%), which is mainly consumed in industry, the power sector, and heating. Oil accounts for 19.8%, with the transport sector as the main consumer, followed by industry. Natural gas accounts for 7.5% of primary energy consumption in 2017 and non-fossil energy accounts for 8% of primary energy supply (or 13.7% using the coal substitution method of accounting). Today's system is overly dependent of fossil fuels, which entail high and rising social costs as well as energy supply risks. Hence the current energy system does not comply with China's goal of implementing a clean, low-carbon, safe and efficient system, implying the need for a radical transition to comply with long-term goals and ambitions.

5.2 The 2050 energy system compared with today's system

The Below 2 °C scenario embodies China's aims to comply with the goal of a clean, low-carbon, safe and efficient energy system. Compared to the present energy system, the Below 2 °C scenario has the following characteristics:

The final energy consumption

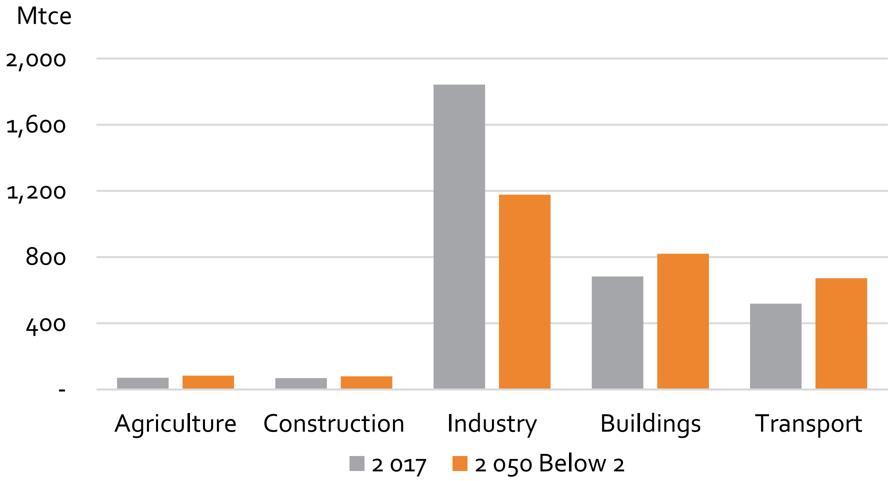
Final energy consumption in 2050 is 2805 Mtce, 374 Mtce lower than 2017, with a 12% reduction from today.

The industry sector less dominant energy consumer

To achieve the development targets set by the 19th China Party Congress (CPC) in October 2017, the Chinese economy is expected to further grow by a factor four by 2050. However, this economic growth need not lead to higher energy consumption in 2050. Economic reforms will transform the economy from reliance on heavy industry to light industry, and from industry to service. Because of the lower energy intensity of the service sector compared to the industrial sector, and high value-added industries lower than traditional industries, structural adjustments will significantly improve the energy efficiency in general and thereby reduce energy consumption. Furthermore, advanced energy-saving technologies and highly-efficient end-use energy devices, will also reduce energy consumption.

China's energy demand will also achieve a more balanced structure. Future energy growth will be centred on transportation and building sectors (both residential and commercial. China's current energy demand by sector is by 2050, the final energy demand in industry, transportation and building sectors will change from the current industry 58%, transport 16%, and buildings 21%; this will shift by 2050 to industry 42%, transport 23%, and buildings 29%. Industrial energy demand will decline steadily, as will the share of energy-intensive sectors.

Figure 5-2: Final energy consumption on sectors (Mtce) in 2017 and 2050 Below 2 °C scenario



Electricity plays an increasingly important role

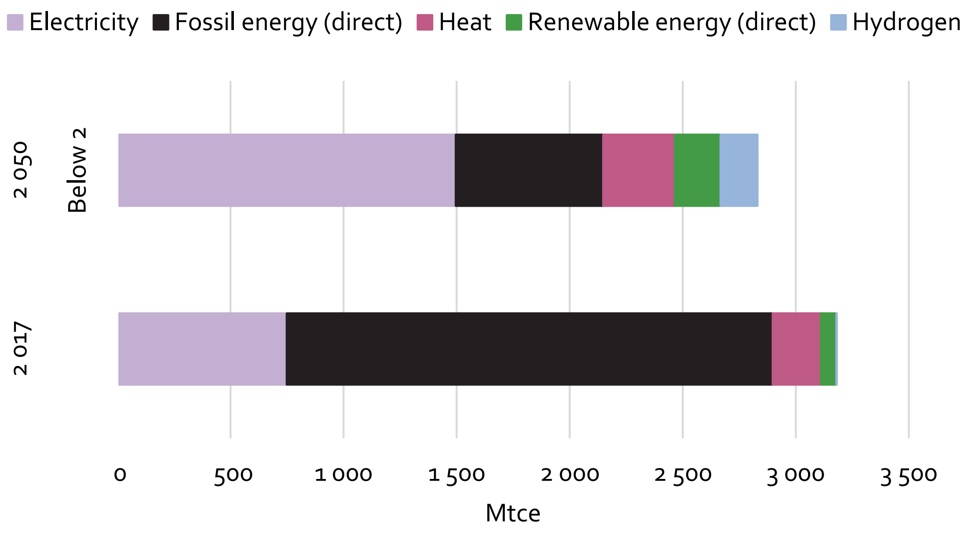
The energy transition radically changes the fuel shares in the end-use sectors. The share of coal declines from 37% to only 3% of the total final energy consumption, while the share of electricity almost doubles from 23% in 2017 to 53% in 2050. From 2017 to 2050, the end-use of electricity demand increases nearly two-fold to 1481 Mtce (12,058 TWh). In addition, hydrogen produced mainly from electricity contributes 163 Mtce to final energy use.

Other secondary energy sources rise strongly. District heating increases its share of final energy consumption from 7% to 11% in 2050. 42% of district heating comes from renewable sources. Hydrogen generated through electrolysis accounts for 6% of final energy consumption in 2050.

Oil consumption in 2050 is essentially confined in the transportation sector, and oil's share of the total final energy consumption falls slightly from 23% in 2017 to 15% in 2050.

The end-use sector thereby sees a transformation from dependence of fossil fuels in 2017 to a more diverse situation in 2050 with electricity as the main energy provider as shown in Figure 3.

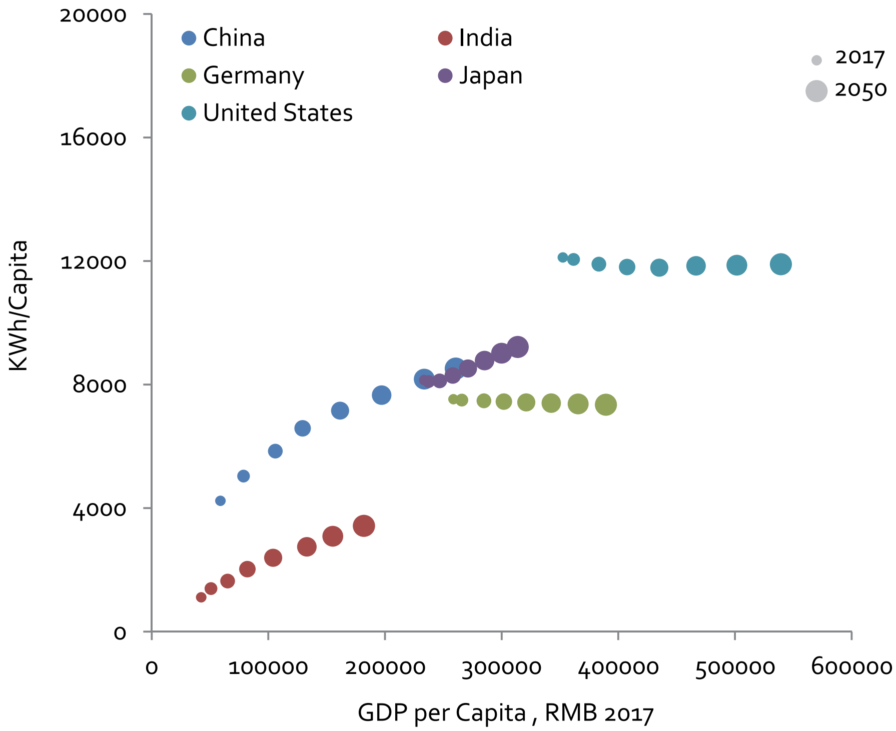
Figure 5-3: Final energy consumption in 2017 and in 2050 in the Below 2 °C scenario (Mtce)



Putting China's electricity development into a global context

Unlike many post-industrial economies, China's future GDP per capita growth remains coupled to an increase in electricity demand per capita, but the electricity demand growth rate slows with time. In 2040, per capita electricity demand doubles relative to today, approaching the current level of Germany and Japan, but still much lower than the U.S. This moderate level of electricity growth enables the Chinese population to achieve a high standard of living while realizing the construction of a resource-efficient society.

Figure 5-4: Relationship between electricity demand and GDP per capita in the Below 2 °C scenario compared with data from IEA World Energy Outlook 2017



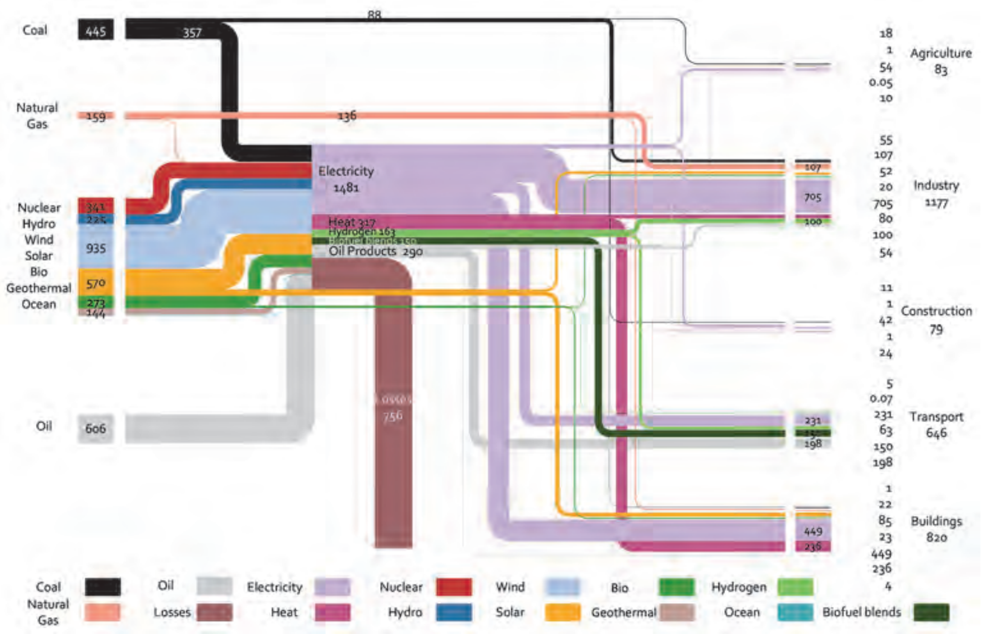
The primary energy consumption

Energy supply transition away from coal

By 2050 China's coal consumption declines to 387 Mtce, accounting for 11% of primary energy supply. It is replaced mainly by electricity in end-use sectors. The non-fossil share of power generation increases to 94%. Natural gas accounts for less than 5% of primary energy consumption, equal to 164 Mtce, lower than the consumption in 2017. The main reason for low natural gas consumption is the relatively high cost of natural gas compared with renewable energy.

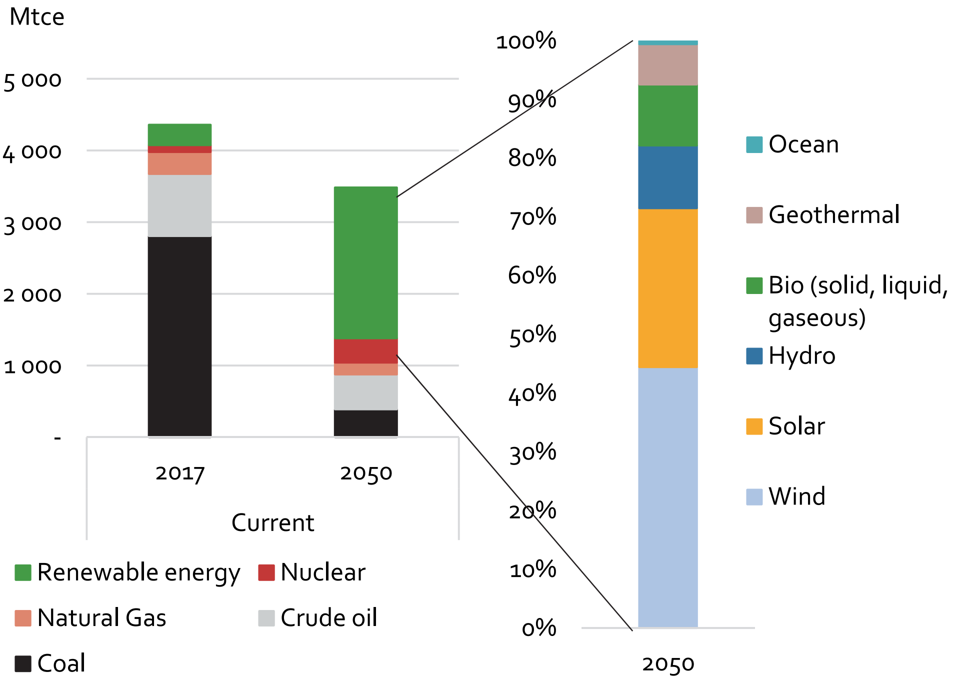
In 2050 oil is mainly consumed in the transportation sector; consumption declines from 864 Mtce in 2017 to 487 Mtce in 2050 in the Below 2 °C scenario, equal to 14% of primary energy consumption. Nuclear energy expands by a factor of 3.6 from today in terms of primary energy consumption (from 96 Mtce in 2017 to 341 Mtce in 2050).

Figure 5-5: Energy flow chart for the Chinese energy system in 2050 for the Below 2 °C scenario



Total primary energy supply decreases by 20% from 2017 to 2050. Given economic growth combined with declining primary energy supply entails large improvements in energy efficiency in the overall energy system. The energy system has higher quality, and uses less energy to support greater economic activity, with fewer negative impacts on the environment, on people's livelihoods, and on energy security. Inefficient production declines, overcapacity is addressed, and system transformation losses fall from 27% in 2017 to 19% in 2050.

Figure 5-6: The primary energy supply (Mtce) on fuels in 2017 and 2050 in the Below 2 °C scenario (left) and the share of different renewable sources in 2050 of total renewable contribution (%) (right)



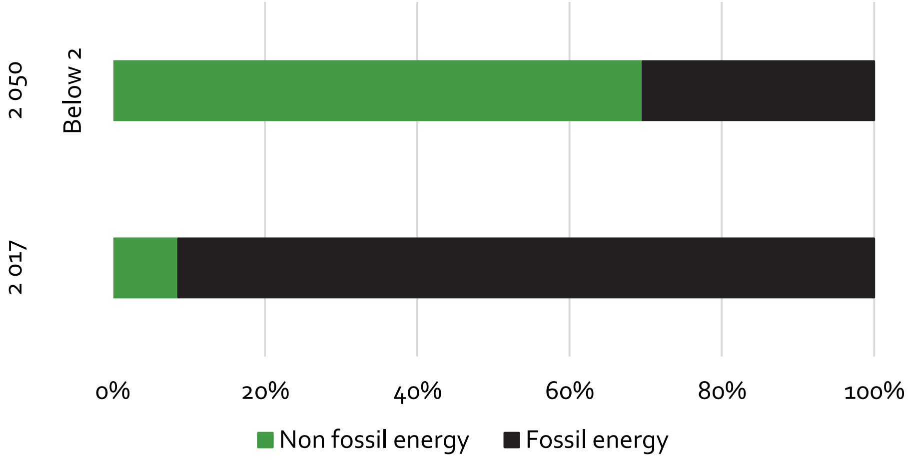
Renewables become the backbone of the energy supply

Renewable energy increases from 288 Mtce in 2017 to 2105 Mtce in 2050 in the Below 2 °C scenario, more than a 7-fold increase. With a 60% share of the total primary energy consumption, renewable energy plays a central role in the energy system.

Wind energy is the largest source of renewable energy in 2050 with a share of 44% of total renewable energy production. Solar accounts for 27%, hydro 11%, bioenergy 10%, geothermal energy 7%, and ocean energy less than 1% of the total renewable energy production in 2050, as shown in 7.

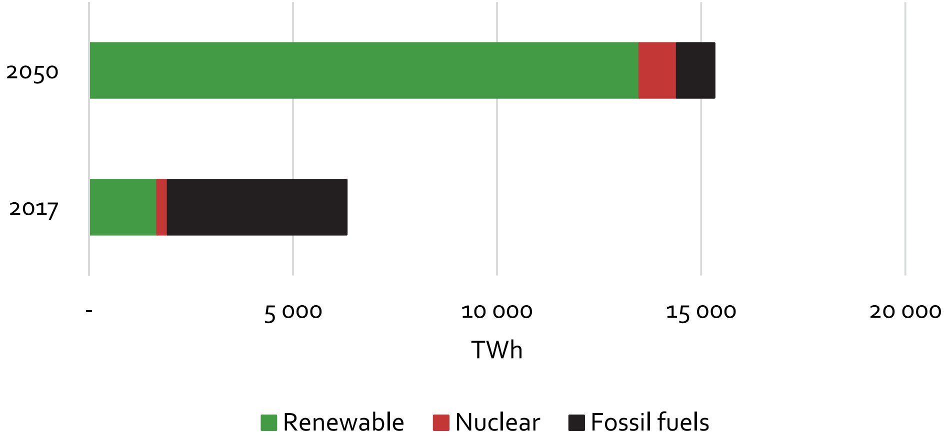
RE in conjunction with nuclear energy enables the non-fossil energy share to exceed two-thirds of primary energy consumption by 2050 in the Below 2 °C scenario.

Figure 5-7: Non-fossil energy in the China in 2017 and 2050 in the Below 2 °C scenario



The share of RE in electricity supply by 2050 is 88%. As renewable electricity becomes the largest source of energy, energy sector development depends on policies to enable efficient system integration, market design, and energy sector regulation.

Figure 5-8: Electricity production (TWh) in 2017 and 2050 in the Below 2 °C scenario divide on fuel types.



5.3 The roadmaps towards 2050

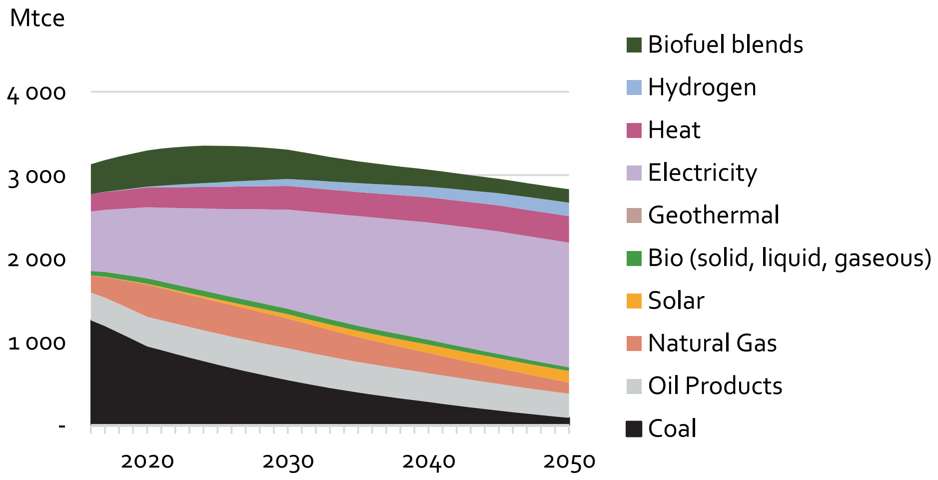
The Below 2 °C scenario gives a clear picture of an energy system that ensures sustainable growth as well as construction of an ecological civilisation by 2050. The next section examines how the transformation from the current system to the 2050 system can take place and compares the Below 2 °C scenario with the Stated Policies scenario.

Final energy consumption

As noted previously, in the Below 2 °C scenario China experiences a rapid phase-out of coal and a corresponding increase of electricity, mainly from renewables. China's total final energy consumption peaks around 2024 and decreases thereafter.

The details in the transformation of the end-use sectors are explained in more detail in Chapter 6.

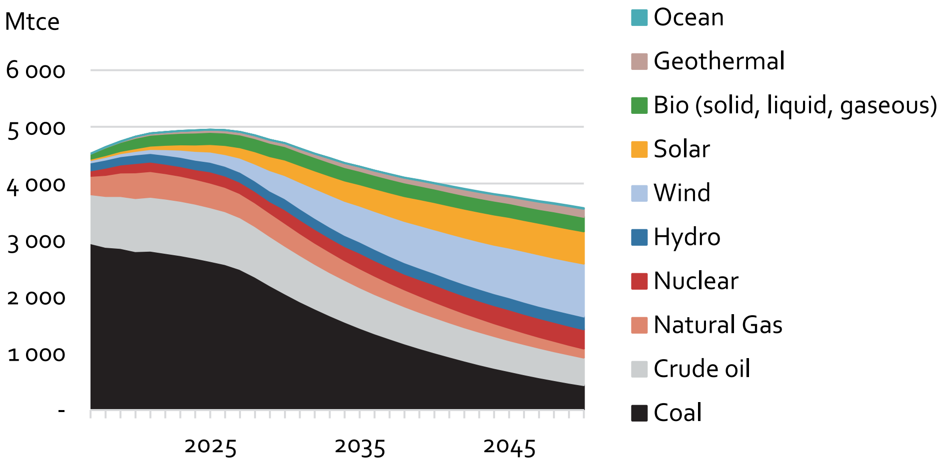
Figure 5-9: The development of the final energy consumption (Mtce) on energy types from 2017 to 2050 in the Below 2 °C scenario



Primary energy consumption

Primary energy consumption shows a slower phase-out of coal due to the large amount of coal power plants in the current energy system. However, after 2020 the deployment of wind and solar power dominate development of new plants and renewable energy becomes the dominant energy source around 2035. China's primary energy consumption peaks in 2020 with a steady decline afterwards.

Figure 5-10: The development of the primary energy consumption (Mtce) on energy types from 2017 to 2050 in the Below 2 °C scenario

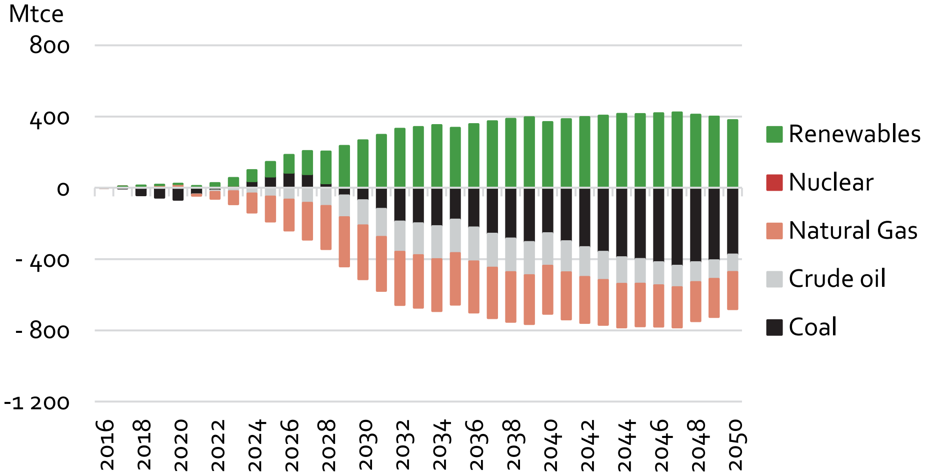


The Stated Policies scenario

The Stated Policies scenario is driven by targets for the energy sector from the 13th Five-Year Plan, including targets for natural gas. China's commitment to the Paris agreement is reflected in the existing National Developed Commitments (NDC) with a reduction in emissions intensity of 40-45% by 2020 and 60-65% by 2030. The Below 2 °C scenario has the same short-term targets to 2020 but after 2020 the targets for CO_2 emission are stricter to ensure compliance with the goals in the Paris agreement to limit the rise in temperature to well below 2 °C. The Below 2 °C scenario does not have target for the minimum consumption of natural gas after 2020.

Because of these two main differences, the Below 2 °C scenario introduces more renewable energy and reduces coal consumption faster than the Stated Policies scenario. From an economic and environmental point of view, natural gas cannot compete with renewable energy in China, either in the end-use sectors or in the power sector. Hence the Below 2 °C scenario reduces the use of natural gas significantly after 2020 compared to the Stated Policies scenario. To reduce the CO_2 emission in the transport sector, the share of electric vehicles rises earlier and more rapidly in the Below 2 °C scenario than in the Stated Policies scenario. The differences between the primary energy consumption is illustrated in Figure 11.

Figure 5-11: Difference in primary energy consumption (Mtce) between Below 2 °C scenario and Stated Policies scenario 2017-2050



5.4 The performance of the energy system in the two scenarios

The following section evaluates the two scenarios and contrasts with the current energy. The evaluation criteria are the policy goals for the system as previously introduced, i.e. the energy system should be clean, low-carbon, safe, and efficient. Additionally, we also consider the impact or benefit from the energy system transition on the overall economy, such as job creation.

A clean energy system

A clean energy system is a system with minimal negative impacts on the environment. CREO 2018 includes analysis of the impacts of the energy system on air pollution and water scarcity.

Air pollution in 2050 is considerably lower in both scenarios

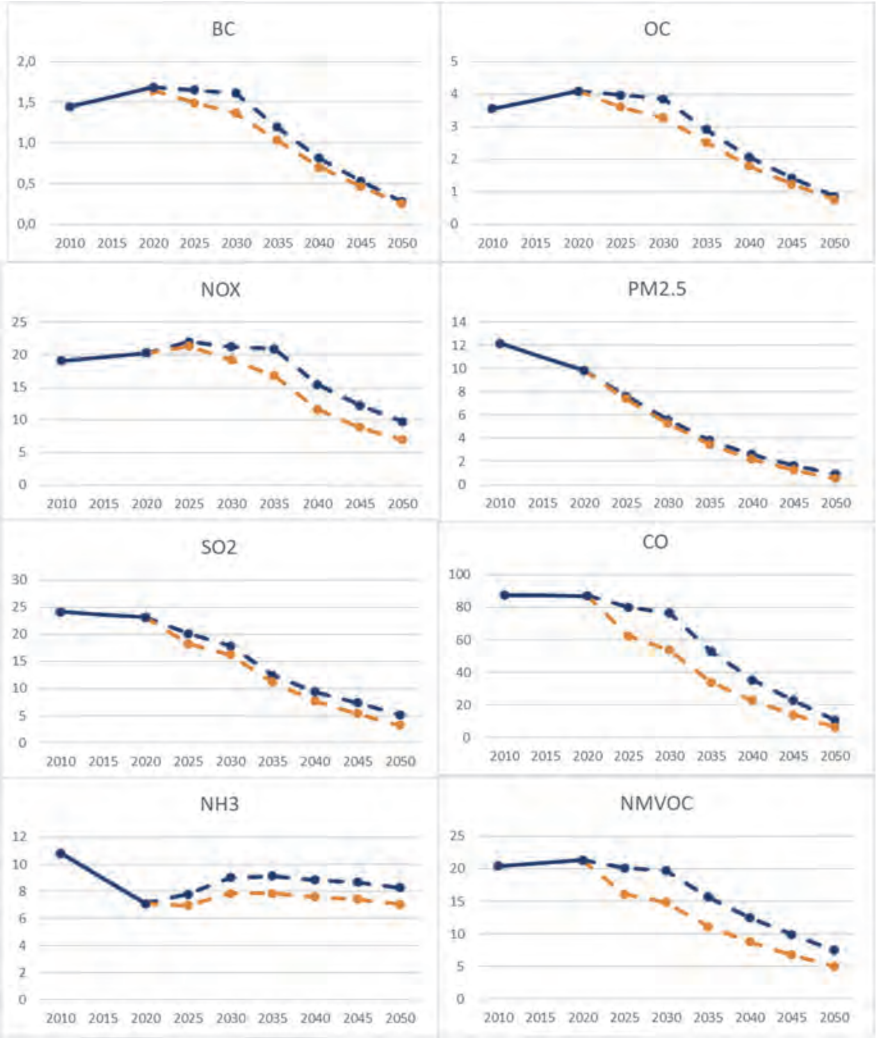
China has undergone rapid economic development, with the unfortunate consequence of growing levels of air pollution. The current levels of air pollution, and their resulting impacts on air quality, public health, and quality of life are a focus area for the government.

Transitioning towards a power system that is primarily based on renewables such as wind, solar and hydro results in significant reductions in air pollutants directly related to power and heat generation. Furthermore, the Stated Polices and Below 2°C scenarios also involve electrification within the transport, residential and industrial sectors, and as a result these sectors also realise reductions in air pollution.

Figure 12 displays the anticipated development in air pollution emissions for 8 different pollutants in the two scenarios. Emissions are based on fuel consumption, estimates regarding future technologies, and known government requirements and standards. The emission of some pollutants, such as particulate matter (PM 2.5), and to a lesser extent sulphur dioxide (SO_2), have been declining since 2010. However, the majority of the air pollutants investigated, including black carbon (BC), organic carbon (OC), nitrogen oxides (NO_x), carbon monoxide (CO) and Non-methane volatile organic compounds (NMVOC) not decline substantially until after 2030. For many of these pollutants, this is related to the large reductions in coal-based power and heat generation that are anticipated to occur in both scenarios during these years.

With the exception of Ammonia (NH_3), where the overwhelming majority of emissions come from agriculture, there are significant reductions in both scenarios for all of the pollutants. A noticeably larger and/or quicker reduction of emissions in the Below 2°C scenario is anticipated to occur for NO_x, CO, NH_3 and NMVOCs.

Figure 5-12: Development in selected forms of air pollution in the two scenarios (million tons/year)



A central reason for the Government to focus on air pollution is the consequential high rates of pollution related illness and premature mortality. Research was undertaken into the current and future health effects related to the emissions of two pollutants (PM 2.5 and ozone), the results of which are displayed in Table 5-1. For PM 2.5, the majority of illnesses are upper respiratory, but also include chronic bronchitis and asthma. Ozone pollution largely results in patients requiring a bronchodilator, and or incurring other serious lower respiratory or asthma related illness.

Table 5-1: Number of estimated cases of serious illness and premature mortality due to selected air pollutants

	Serious illness (annual cases per thousand people)			Premature mortality (annual cases per million people)		
	2017	**2035**	**2050**	**2017**	**2035**	**2050**
PM 2.5	37	15-19	2-5	1200	445-580	55-140
Ozone	290	195-265	55-105	240	150-205	40-80

The findings indicate that both scenarios will result in large reductions in per capita cases of serious illness and premature mortality related to PM 2.5 and ozone emissions, with the Below 2°C scenario anticipated to see roughly 50% fewer cases than the Stated Polices scenario.

Societal costs associated with the cases of serious illness and premature mortality were also supplemented have been estimated (see Table 5-2). For serious illness, the costs include associated medical expenses incurred to treat the illness. The societal loss related to premature mortality is estimated via the Value of Statistical Life (VSL) method, which is an expression of the individual willingness to pay to avoid premature death. The VSL is based on Chinese surveys and studies and is adjusted for each province to reflect regional socio-economic differences. The average VSL for China in the study was estimated at slight over US$ 250,000.

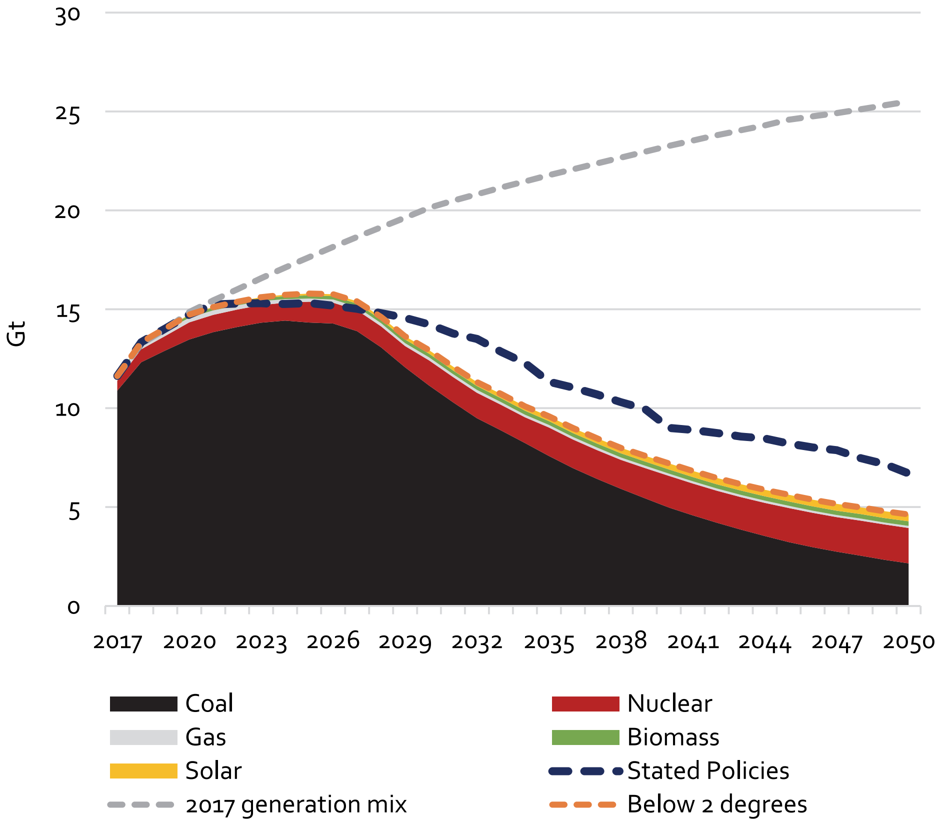
Table 5-2: Estimated costs associated with serious illness and premature mortality due to selected air pollutants

Billion RMB 2015	**2017**	**2035**	**2050**
Serious illness	50	90-100	50-100
Premature Mortality	5,980	4050-5340	740-1700
Total	**6,030**	**4,140-5440**	**790-1800**

Great improvement of water usage in the power sector

Much of China suffers from high water stress, and this should be a consideration in energy sector policy. In both CREO scenarios, total water consumption for energy falls despite a doubling of power production. This is primarily due to a shift away from coal, which is a water intensive generation technology. Various estimates for water consumption (high, medium, and low depending on assumptions for water intensity) have been undertaken. Figure 5-13 displays the medium estimates for water consumption for the two scenarios. Just how large water demand could become if the current generation mix was maintained has also been investigated, and this scenario is also displayed in the figure.

Figure 5-13: Estimated water consumption from the power generation sector in the Stated Policy and Below 2°C scenarios, as well as a hypothetical situation where the generation mix from 2017 is frozen through to 2050. The results depend on underlying assumptions for water intensity, with the figures displaying the medium estimates.



The figure highlights the significant decoupling between electricity generation and water demand that will otherwise not occur in China in the absence of a shift away from coal-based generation (reflected by the grey 2017 generation mix line). With water scarcity already being an issue in several regions in China today, a development in water demand of this nature would unlikely to be feasible.

In the Below 2°C scenario, power sector water consumption is reduced much quicker after 2028 relative to the Stated Policies scenario and continues to be much lower throughout the analysis period.

The figure also highlights the growing portion of water demand that will accrue to nuclear-based electricity production. In determining which low CO_2 emitting electricity generation technologies should replace coal, the significant amount of water required for nuclear power is an important factor to be considered, particularly if policies would open for inland water intensive nuclear.

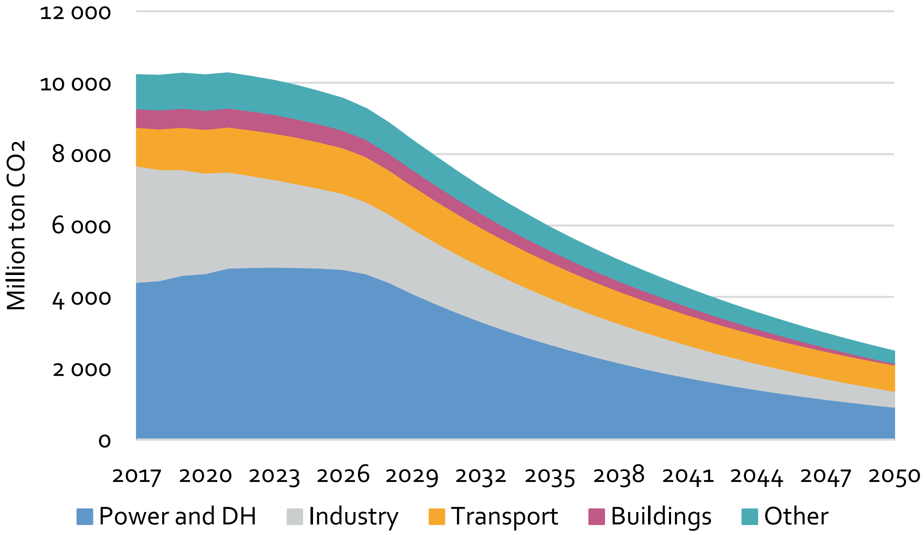
A low-carbon energy system

CO_2 emissions decline significantly from the current levels by 2050

In the Below 2 °C scenario, CO_2 emissions decline significantly in all sectors. The scenario is constrained by a CO_2 budget determined by a cap on the cumulative CO_2 emission in the period, according to global CO_2 emissions reductions needed to comply with the Paris agreement's goal of limiting the increase in global temperature to well below 2 °C. The cumulative cap is estimated at 230 gigaton of CO_2 in the period 2017-2050, based on the estimates in CREO 2017. This cumulative cap is distributed throughout the period to allow a smooth trend of energy system development. Since the cumulative amount is fixed, any delay to CO_2 emission reduction puts even more pressure on the medium- and long-term reduction requirements.

Figure 14 shows the annual emission in the Below 2 °C scenario, whose cumulative value is constrained by the CO_2 cap. The power sector and industry dominate 2017 carbon emissions, due to the high share of coal and the low thermal energy efficiency in these sectors. In 2050, total emissions decline to 2,547 million tonnes, and by then most emissions come from the transport sector together with the power sector. The power sector and industry achieve the largest reductions, but all sectors see improvements in 2050 compared to 2017.

Figure 5-14: CO_2 emission in the Below 2 °C scenario 2017-2050 on sectors



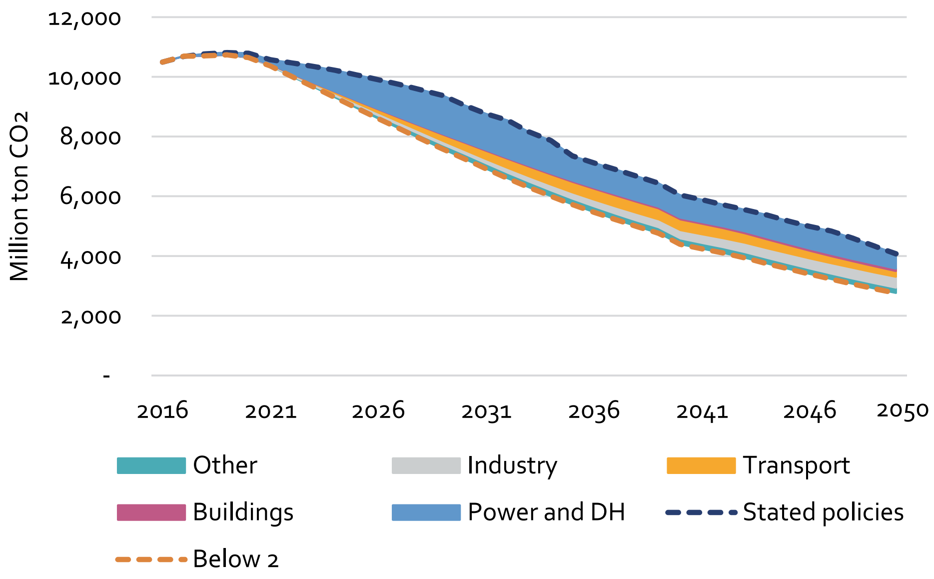
The Stated Policies scenario cannot comply with the Paris agreement goals

The Stated Policies scenario has softer CO_2 emission targets related to China's current NDC commitment to the Paris agreement, which calls for a peak in emissions before 2030 and a reduction of CO_2 emission intensity of GDP compared with 2005. Combining the economic development objective with the commitments towards emissions intensity reductions is insufficient to achieve the needed absolute emissions reductions. However, the Stated Policies CO_2 emission is lower than these constraints due to other drivers, including cost optimisation embedded in the power system model, which reduces the use of fossil fuel. Hence CO_2 constraints are not binding for energy system development in the Stated Policies scenario.

The Stated Policies scenario has higher CO_2 emissions than the Below 2 °C scenario and the Stated Policies scenario is unable to fulfil the requirements for CO_2 emission from the Paris agreement goals for a well below 2 °C future.

The difference in CO_2 emission in the two scenarios on the different sectors is shown in Figure 15. The difference is evident in all sectors, but the predominant additional CO_2 reductions are in power and industry, the main emitting sectors.

Figure 5-15: CO2 emissions development in the Stated Policies scenario and the Below 2 °C scenario.



Emissions of CO_2 in the Stated Policies scenario indicates that decarbonisation aligns with other policy imperatives. Reducing carbon emissions does not impose an undue cost burden on the Chinese economy. China could take leadership in announcing more ambitious targets for emissions reductions, given this alignment with domestic policy priorities. The Below 2 °C highlights the importance of early action, which is necessary to avoid abrupt and disruptive emissions reductions. For example, early action helps avoid stranding investments.

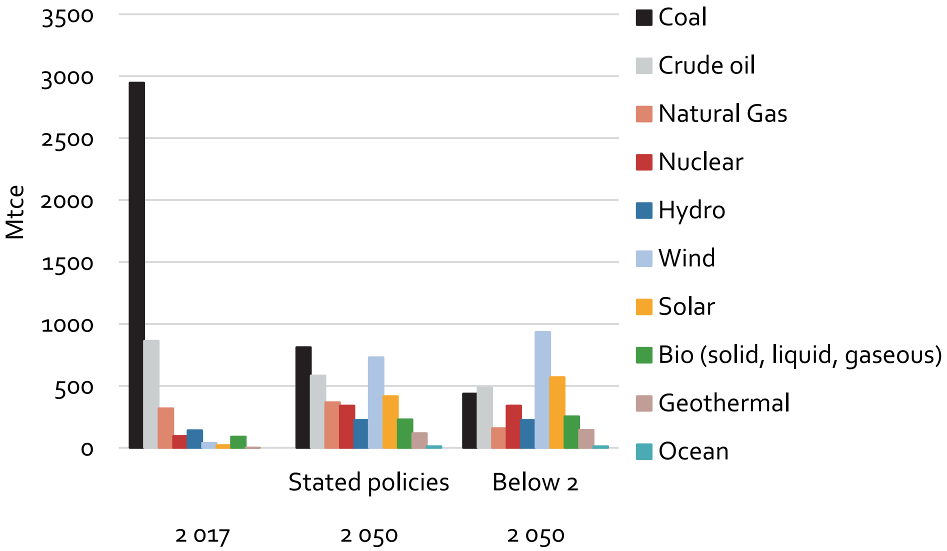
A safe energy system

A more diverse energy supply

An energy system with diverse energy sources would be less vulnerable to volatile fuel prices, geopolitical supply crises, or unreliability due to weather conditions.

The energy system in 2050 is much more diverse regarding the mix of different energy sources compared to the situation today, where coal and other fossil fuels dominate the energy supply. Dependence on fossil fuels declines to 30% in the Below 2 °C scenario and to 46% in the Stated Policy scenario.

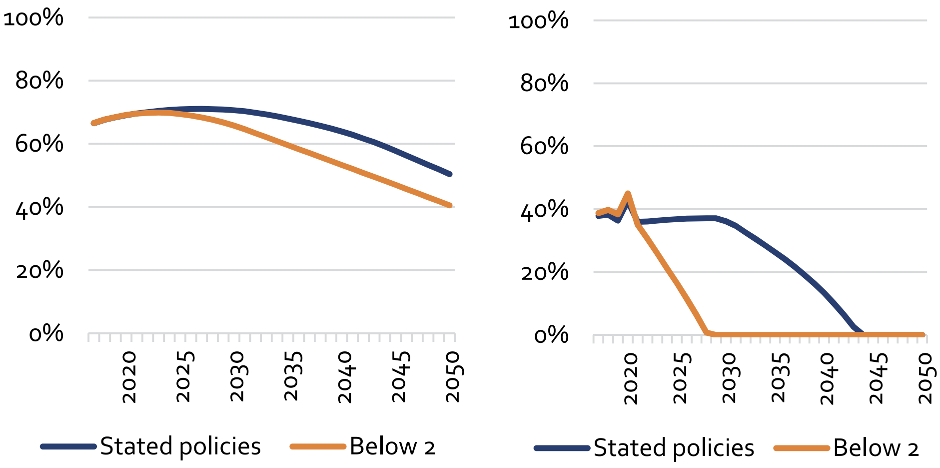
Figure 5-16: Diversity of fuels in Primary energy consumption in the two scenarios in 2050 compared with 2017



Dependency of imported energy

In 2017, China's depended on energy imports for 20% of energy. Fossil fuel imports account for 23% of fossil energy consumption. Oil imports account for almost 67% of national oil consumption. About 40% natural gas is imported. Coal imports accounted for about 7% of annual coal consumption.

Figure 5-17: Import share for crude oil and natural gas in the two scenarios from 2017 to 2050



Oil imports hover around the 70% level until 2030, where after the transformation of consumption patterns in the end-use sectors start to take hold.

Given the increased role of natural gas in the short and medium term, import dependence is slated to increase, peaking between 2020 and 2035, with 38% of natural gas imported despite a significant ramp-up in domestic production.

In the long-term, China achieves a complete transformation of its energy system. By transitioning to renewables and electricity, China reduces long-term gas and oil import dependence, increasingly overall security of supply. However, China will still be dependent on imported oil for many years.

Reliability

Short-term reliability is also part of a safe energy system. In the scenario analyses, the system's ability to react to 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. See more about this in the Power Sector Outlook.

Overall evaluation

In general, the future energy system is safer than the current energy system due to a more diverse fuel supply and lower dependence on imported fuels. The Below 2 °C scenario tends to be a safer energy system than the Stated Policies scenario, even though it is difficult to quantify the differences between the two scenarios, since it will be highly dependent on the geopolitical situation in 2050.

An energy efficient energy system

Accelerating gains in energy efficiency offset energy demand growth

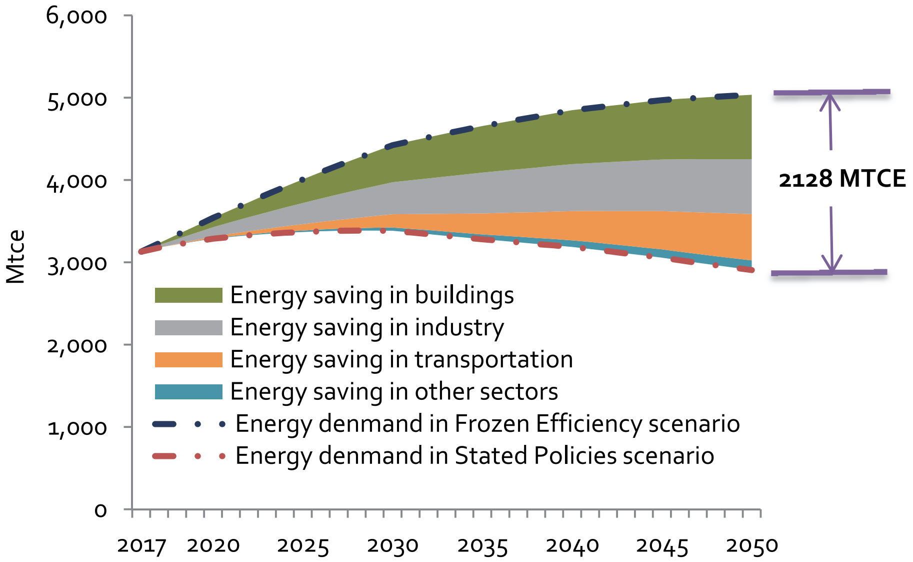
Primary energy consumption declines to 15% of the 2017 level by 2050. Meanwhile, economy quadruples in terms of gross domestic product (GDP). China can achieve this transition only through major energy efficiency measures as well as structural shifts away from energy intensive industries in the economy.

In our two scenarios, energy efficiency offsets increasing demand for many end uses. It compensates for the inertia in the industrial supply chain and enables the system to radically shift the energy mix. Efficiency also mitigates energy consumption growth in the buildings and transport sectors, and finally flattens the upwards trends in final energy consumption between 2017 and 2050.

To highlight the necessity for energy efficiency improvements, here we introduce a frozen efficiency scenario. In this scenario, all the economic activities follow the same path as the main scenarios, but without further energy saving efforts from the base year. This implies a halt to efficiency technology improvement on the end-use side, whether conventional efficiency gains or electrification. Meanwhile the proportion of end-use devices satisfying specific energy demands in different sectors also remains constant with no further electrification.

The final energy demand in the frozen efficiency scenario is about 5035 Mtce, while in the Stated Policies scenario it is 2908 Mtce. An energy saving potential of 2128 Mtce will be released through energy efficiency measures, which is breaks down to 668 Mtce in industry, 564 Mtce in transportation, 782 Mtce in the building sector , and 115 Mtce in other sectors.

Figure 5-18: Energy saving potentials by efficiency improvement for the Stated Policies scenario



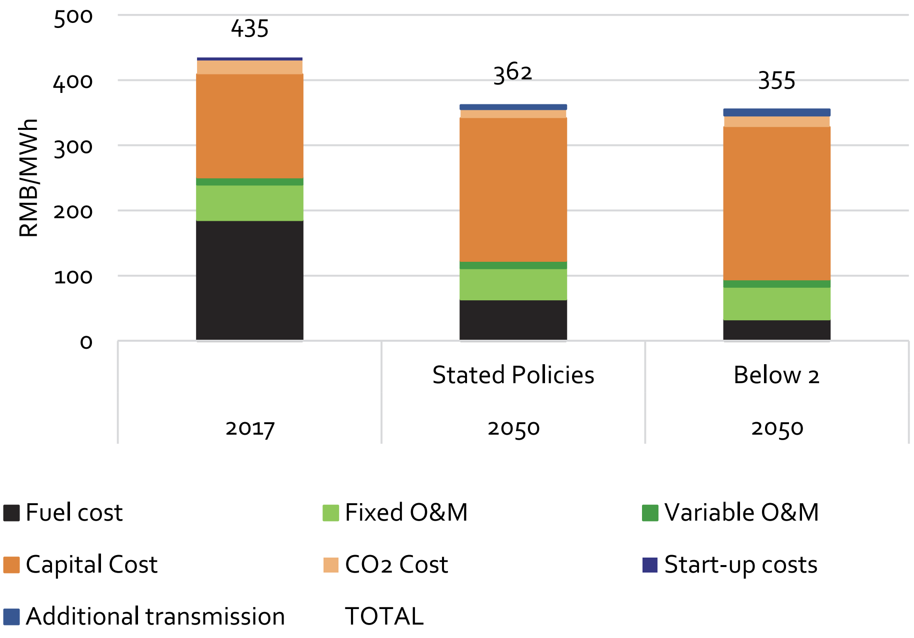
The Below 2 scenario's increased electrification brings further 103 Mtce reduction in final energy consumption.

A cost-efficient energy system

Modernised electricity supply with lower costs

In the two scenarios presented here, the electricity system sees improved quality of supply without higher electricity costs. The shift towards efficiency and renewable energy means that more money goes to infrastructure and upfront investment costs, as opposed to fuel costs. Infrastructure spending includes upfront investments for wind turbines, solar plants, storage and grids. More money also goes into software costs: advanced system operations including, fast and efficient market operations platforms, forecasting, efficient dispatching, smart grid management, load management, smart charging of EVs, and other demand response measures. Generally, these software investments go together with the considerable investments in hardware to ensure economically efficient asset utilisation. Less money is used on fuel extraction, storage, and delivery. Importantly, these figures exclude external costs relating to environmental degradation and climate change. These costs also fall is significantly as the energy transition progresses.

Figure 5-19: Cost of energy supply per MWh estimated in 2017 and for the two scenarios in 2050.



In the figure above, costs indicated include all contributions from energy generation and storage including CO_2, but excluding external costs relating to other pollutants.

Driven by continued cost reductions in RE technologies and the gradual retirement of uneconomical assets, it is possible to supply electricity at costs which are lower than today. In both the Stated Policies scenario and the Below 2 scenario the cost of electricity supply is lower. The more stringent focus on CO_2 emissions reductions in the Below 2 scenario, promotes a more rapid transition to a green, clean and efficient energy system.

5.5 Job creation and other socioeconomic benefits

An input-output model is used to analyse and assess the economic output of the energy sector, the impact of the energy industry on other macroeconomic sectors, and employment in the two scenarios. We divide the upstream industries affected by the RE power generation into four groups: manufacturing, construction, operation and maintenance, and power generation.

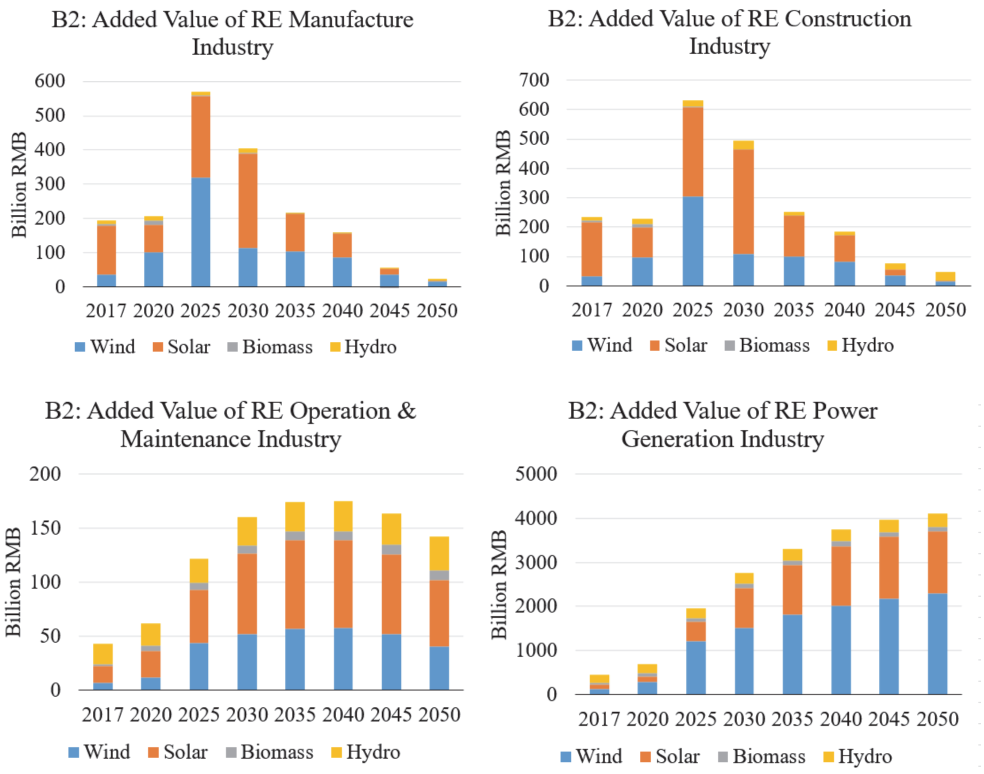
- The output value of the RE manufacturing industry depends on the sales volume and sales price of various RE equipment.
- The RE construction industry depends on the increment of power generation capacity and the construction cost of the project.
- The RE operation and maintenance industry depends on the total installed capacity and the operation and maintenance costs of the project.

- The output value of the renewable power generation industry depends on the energy output and sales prices of various renewable energy technologies.

Direct macroeconomic impacts

Figure 20 shows the changes in the output value and added value of the renewable power manufacturing industry and the power generation industry in Below 2° C scenario. In Below 2° C scenario, the added value and output value of renewable energy power generation manufacturing industry increase first and then decrease. In 2025, the added value of renewable energy power generation manufacturing industry reaches a peak value of RMB 570 billion, and then decrease to RMB 24.4 billion in 2050. In contrast, due to the rapid increase in the scale of power generation, the added value of the renewable energy power generation industry steadily increases, from less than RMB 500 billion in 2017 to more than RMB 4 trillion in 2050.

Figure 5-20: Added Value of Renewable Energy Power Industry in Below 2° C Scenario from 2017 to 2050

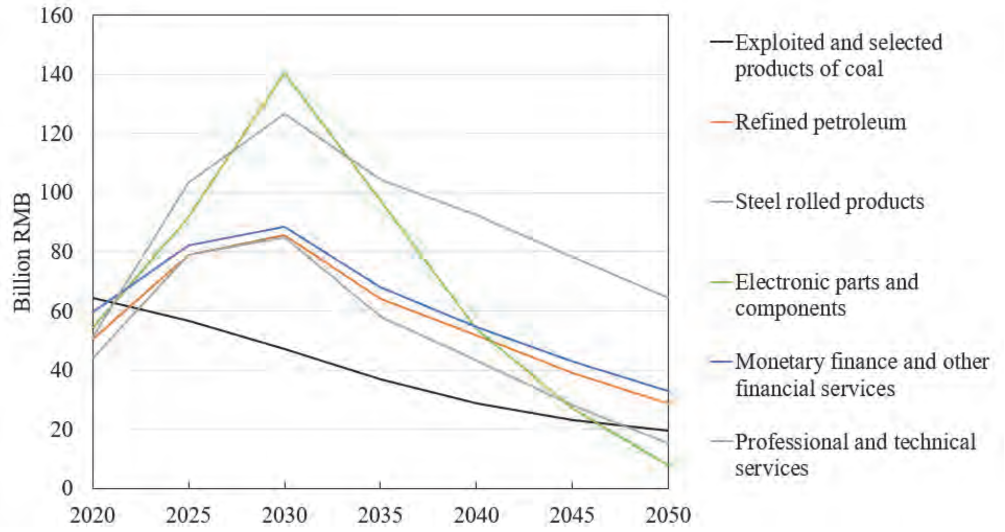


Indirect macroeconomic impacts

Renewable energy is closely related to many manufacturing sectors. The increase in the scale of renewable energy has driven the development of renewable energy production sector and related upstream industries. Upstream industries of wind power generation include blade manufacturing, while upstream industries of solar photovoltaic power generation include photovoltaic cell production, crystalline silicon purification, smart meters and other electronic equipment production. All will develop rapidly under either scenario. Traditional energy sectors will be negatively affected, especially coal mining and coal-fired power generation.

Figure 21 displays six sectors with significant impact difference at different stages, namely coal mining, refined petroleum, steel rolling products, electronic components, financial services, and professional technical services. Taking electronic components as an example, as the new installation of renewable energy power generation is fast in Below 2 ° C scenario before 2030, the industrial pull effect in the early stage is obvious, and peaks around 2030. As the pace of new installed capacity decreases after 2030, the demand for electronic components continues to decrease. Similarly, the first increase and then decrease in the growth rate of renewable energy power generation capacity will have similar effects on sectors such as refined oil and steel rolling products. Conversely, for coal mining products, there is a significant reverse pull effect, in that the development of renewable energy leads to the plummeting demand for coal mining products in the overall energy sector after 2020.

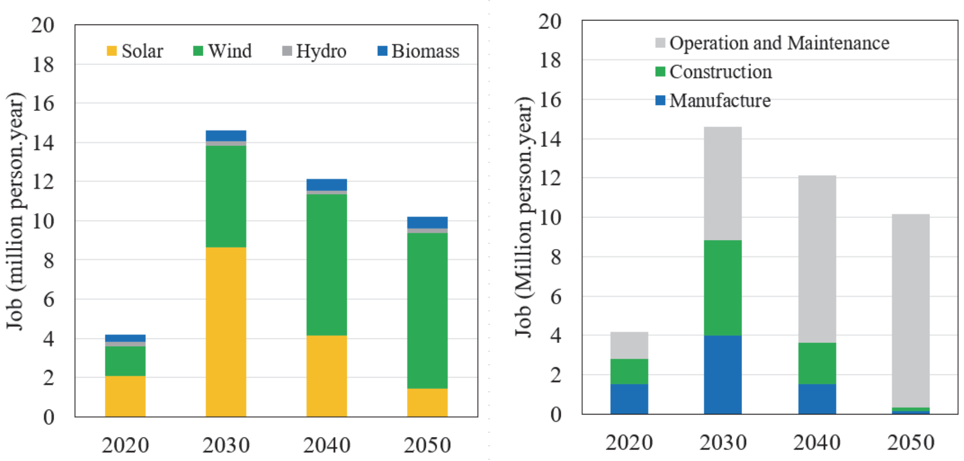
Figure 5-21: Main sectors affected by the renewable energy industry in the Below 2 °C scenario from 2020 to 2050



Employment Impact

In the Below 2° C scenario, total employment in the renewable energy power generation field in 2030 is close to 16 million, about 30% higher than that in Stated Policies scenario. This leads to net total employment difference in 2050 of 8 million due to lower new installed capacity. Most employment gains are in the field of operation and maintenance. In terms of jobs in the renewable energy industry, the dominant employment is in renewable energy manufacturing. Renewable power operations are not very labour intensive. As a result, employment in renewable energy will initially increase, and then decrease as the wind and solar build-out slows.

Figure 5-22: Employment Scale of Renewable Energy in Below 2 °C Scenario from 2017 to 2050



In summary, the rapid development of the renewable energy industry will play a positive role in promoting macroeconomic development, though with differing impacts at each stage of the energy transition. From 2025 to 2035, the rapid growth of manufacturing scale will boost the demand for employment in sectors directly or indirectly related to renewable energy, and this positive effect is greater than the decrease in employment in fossil energy such as coal and thermal electricity.

Secondly, the development of renewable energy industry will help to improve the quality of macroeconomic development. The renewable energy supply chain covers electronic components, information and communication, computers, professional technical services and other industries. These sectors feature high added value and potentially strong sustainability. A transition that supports these fields also promotes the overall adjustment of the country's macroeconomic structure. Thirdly, there is room for improvement in renewable energy technologies. Falling costs will increase the operating efficiency of the energy industry, to create development space for the provision of value-added services such as energy information and data analysis based on basic energy services, distributed energy and energy production and consumption (prosumer) services, energy storage, and EV charging.

The transition in employment will necessitate changes in education and training. In the near and medium term, the rapid development of renewable energy will generate significant employment in related equipment manufacturing, project construction and operation and maintenance industries. The overall employment demand of the renewable energy industry will continue to grow over the long-term. To anticipate these changes in energy employment structure, relevant government departments should adjust academic requirements and vocational training, to increase the supply of specialists and professionals for this field. In addition, China will need to boost training of researchers and technological specialists. China will need to improve education in fields related to renewable energy education, establish renewable energy majors and high tech centres at leading national universities, and encourage vocational education institutions and large-scale renewable energy enterprises. Such changes will help meet the medium and long-term employment needs in fields such as project operation and maintenance.

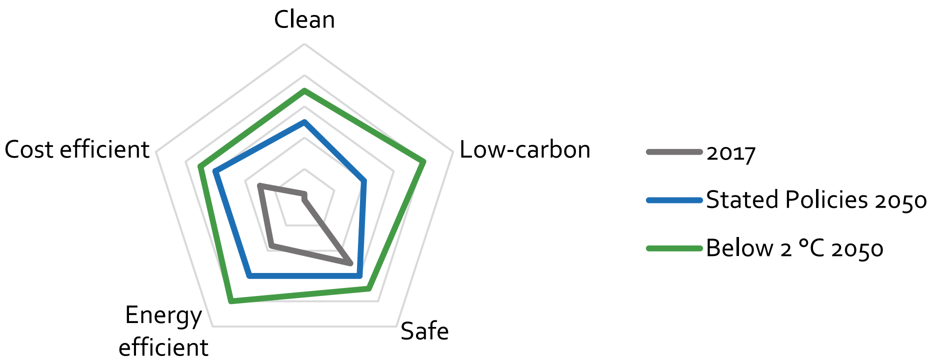
5.6 Overall assessment

The current energy system does not comply with the long-term goals for the energy system. Especially regarding air pollution and emission of CO_2 from the energy sector the current energy system is very far from the goals, but the current system is also vulnerable due to high share of imported oil, and the system is inefficient regarding energy utilisation and cost-efficient operation.

In contrast, the Below 2 °C scenario performs very well according to each criteria, and while the Stated Policies scenario has a clear improvement compared to the current system, it is outperformed by the Below 2 °C scenario on all criteria. This illustrates that an effort to reduce CO_2 emission also will have a positive impact on other priorities in the long-term, including power system costs.

The relative performance of the current system and the two scenarios in 2050 against the key evaluation criteria is illustrated in Figure 5-23.

Figure 5-23: Assessment of the energy system in 2017 and in 2050 in the two scenarios according to the key criteria for a sustainable energy system for China



5.7 Renewable energy targets in 2020-2035

Targets for 2020 and 2030

Compared with the target for renewable energy in the 13th Five-Year Plan, the scenario results suggest higher targets for wind, solar, and biomass and a higher target for the share of non-fossil fuel in 2020. For 2030, the non-fossil fuel share could be more than twice the official target, according to the Below 2 °C scenario.

Table 5-3: Targets for renewable energy and non-fossil fuels in the 13th Five-Year Plan from 2015 compared with scenario results for 2020 in the two CREO scenarios

2020	13th five-year plan Policy targets	Stated Policies Scenario	Below 2 °C Scenario
Renewable power capacity			
Total Capacity	676 GW	870 GW	897 GW
Hydropower	340 GW	343 GW	343 GW
Wind	210 GW	225 GW	221 GW
Solar	110 GW	232 GW	229 GW
Biomass	15 GW	48 GW	48 GW
Other RE	0.55 GW	0.55 GW	0.55 GW
Share of Total Energy consumption			
Non-fossil Fuel 2020 (coal substitution method)	15%	19%	19%
Non-fossil Fuel 2030 (coal substitution method)	20%	33%	43%

Targets for 2035

China has set 2035 as the year for the development of China into a modern society. Policy-makers have yet to establish targets for renewable energy for 2035, but the two CREO scenarios gives a framework for discussion about such medium-term targets.

Table 5-4: Renewable energy capacities in 2035 in the two CREO scenarios

2035	Stated Policies Scenario	Below 2 °C Scenario
Total Capacity	3190 GW	4362 GW
Hydropower	454 GW	454 GW
Wind	1162 GW	1826 GW
Solar	1494 GW	2000 GW
Biomass	62 GW	64 GW
Other RE	18 GW	18 GW
Non-fossil Fuel (coal substitution method)	39%	57%

6 Energy demand outlook

6.1 Summary

China's current energy consumption paradigm is inefficient and unsustainable

In 2017, China's final energy demand is about 3178 Mtce. Fossil fuels accounted for 55.8%; coal and coal products accounted for approximately 37.5%. China's current energy intensity is relatively high compared to Europe, Japan, or North America. Were China to meet the 2050 economic targets set by 19th CPC (Communist Party of China) with its the present energy intensity of GDP, China's final energy demand would exceed the total energy consumption of the entire world today – far beyond China's energy supply capability. Hence, it is imperative for China to transform to a paradigm of efficient, high-quality, and sustainable energy consumption.

Energy consumption revolution increases efficiency in the Stated policies scenario

Acknowleding this imperative, China's government has adopted a long-term strategy of revolutionizing energy consumption and production, and issued a series of policies to support this vision. If these policies are fully implemented, China's final energy demand will undergo a fundamental change by 2050.

By improving energy efficiency, under the Stated Policy scenario China's final energy demand peaks at 3385 Mtce by 2028, and then declines to 3187 Mtce by 2040, and 2907 Mtce by 2050. China structural energy demand also rebalances: Energy demand by sector will shift from 60% in industry, 16% in transportation, and 21% in buildings in 2017 to 42% in industry, 24% in transport, and 28% in buildings in 2050. Industrial energy demand will decline steadily, and the share of energy-intensive sectors will also continue to decline.

China will also have a cleaner and safer end-use fuel mix: In 2050, 6% of the final energy consumption is coal, 17% is oil, 51% electricity, 9% natural gas, 12% district heating, 3% hydrogen, and 5% renewables.

Further actions result in more carbon reduction in Below 2 °C scenario

To comply with the carbon budget in the Paris Agreement, China will need further measures to reduce fossil fuel combustion in the end-use sectors. Electrification and accelerated technology replacement in transport and industry are the main measures needed, and these can reduce energy demand by 48.5 Mtce in the industry and 46 Mtce in transport. This results in a reduction of the final energy demand to 2805 Mtce in 2050 in the Below 2 °C Scenario, 3.6% less than in Stated Policies Scenario. Hence, the Below 2 °C scenario has an earlier peak in final energy demand in 2024 at 3329 Mtce.

This scenario also results in a cleaner fuel mix, with higher electricity and hydrogen accounting for 59% in 2050, versus 51% in the Stated Policies scenario. The Below 2 °C scenario also sees fossil fuel fall to a 23% share, versus 33% in the Stated Policies scenario. In 2050, direct CO_2 emissions from the end-use sectors is reduced by 625 million tonnes to 1252 million tonnes relative to the Stated Policies Scenario.

Electrification is the key driver in the energy consumption revolution

In the Stated Policies scenario, from 2017 to 2050, end-use electricity demand nearly doubles to 1395 Mtce (11,355 TWh), and in the Below 2 °C scenario it is 1481 Mtce (12,057 TWh). Hydrogen production consumes 102 Mtce (830 TWh) and 222 Mtce (1,808 TWh) of electricity in the two scenarios, and meets 75 Mtce and 164 Mtce of the final energy demand. To further provide flexible electricity consumption and efficient energy storage, by 2050 district heating systems consume another 50 Mtce (486 TWh) and 75 Mtce (610 TWh) electricity in the two scenarios, respectively.

The share of electricity in conjunction with hydrogen in the final energy use of China rises from 23% in 2016 to 51% in 2050 in stated policies scenario; in Below 2 °C scenario, it further increases to 59%.

In both scenarios, China's end-use electricity consumption surpasses the demand for coal combustion for end-use energy around 2022, and the proportion of coal in end-use energy continues to decline thereafter.

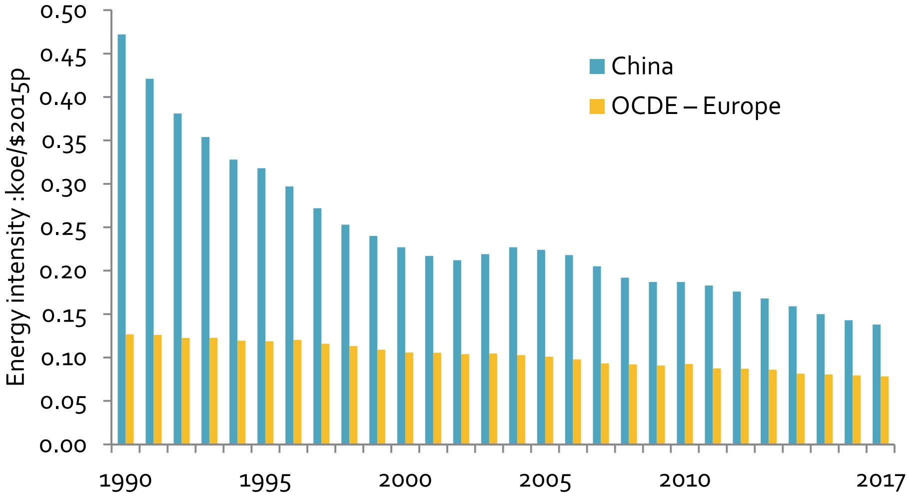
6.2 Today's energy dependency requires fundamental changes

China's economy heavily depended on energy and the energy intensity is high

Today, China faces an energy dilemma in final energy consumption, in that its current economic growth is strongly coupled to energy consumption. In the 40 years since the beginning of the Reform and Opening policy, China's GDP increased by a factor of 35 while primary energy consumption rose from 570 Mtce to 4,490 Mtce from 1978 to 2017, a factor of eight.[125]

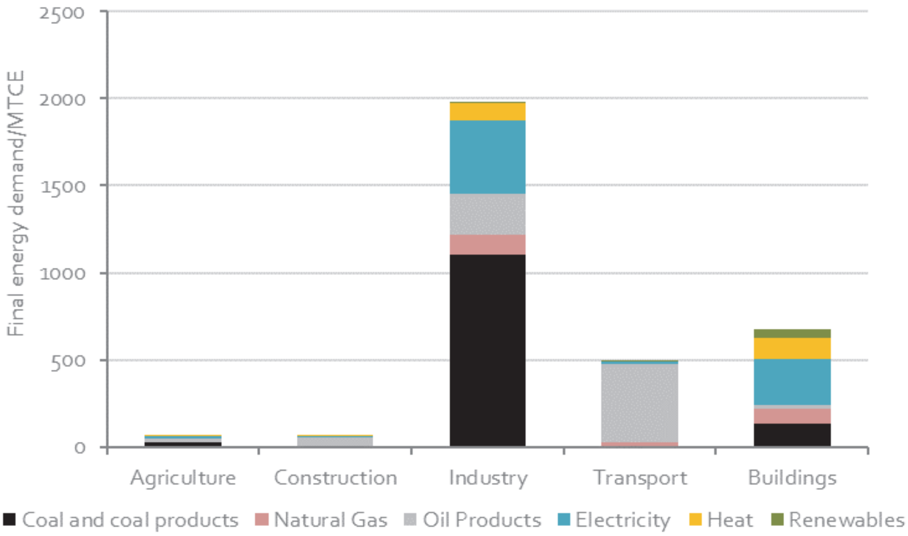
Although economic growth is linked to the increase in China's energy demand, it relates also to China's economic structure, with industry accounting for between 40-50% of China's GDP. The rapid development of industry has driven the economic development, but also caused a sharp increase in energy consumption. In 2017 industry consumed 59% of total final energy demand. The service sector share of China's GDP has grown, and reached 52% in 2016, but this proportion is smaller compared to advanced, post-industrial economies, where service sectors share in GDP is around 70%. Compared to these countries, China's economy has low energy efficiency. A considerable part of primary energy is wasted through low-efficiency upstream infrastructure, as well as inefficient end-use technologies. In 2017, China's energy intensity of GDP is 1.8 times higher than OECD-Europe.

Figure 6-1: Energy intensity per GDP in China and OCDE [126]



China's energy system still relies heavily on fossil fuels, in particular coal. Coal dominates China's energy consumption, even when disregarding power generation and district heating, as coal-fired boilers are used widely by heavy industry plants, commercial and residential areas. In 2016, the final consumption of fossil fuels took up approximately 57.3%, and coal products took up approximately 40.2%. China has high electricity consumption, specifically in the industrial and residential sectors. Renewable energy other than electricity, including biomass, solar heating, and geothermal heating, currently provides a small portion of final energy consumption—mostly for residential heating in rural areas and smaller cities.

Figure 6-2: Final energy demand in main fields of China in 2016



A strategy for the Energy demand transformation

The development history of high-income countries shows energy demand has tended to grow with industrialisation and urbanisation, and to stabilise in tandem with tapering growth in industrialisation and urbanisation. The intensity of final energy consumption also tends to rise initially and to decline in later stages. China is currently at the middle or late stage of industrialisation and urbanisation, with over half the population living in urban areas and the non-industrial sectors capturing a growing share of GDP. Though China's energy demand is still increasing, energy efficiency is improving and energy intensity of GDP is declining.

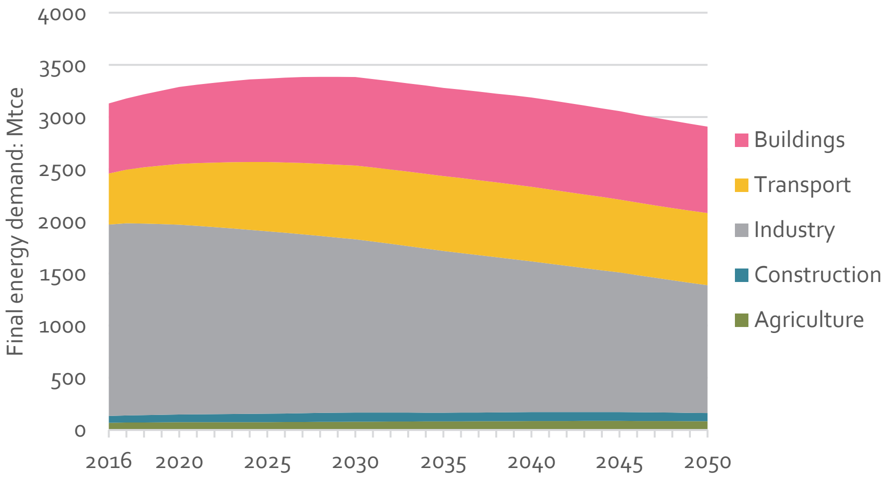
In the energy transition, policy-makers must pay equal attention to energy demand and supply, optimise the economic and industrial production structures, cultivate green and clean energy consumption patterns, encourage innovation in energy supply and demand technology, and pursue policies to improve the structure of energy consumption. For the next few years, it is urgent to control coal consumption in the end-use sectors, promote coal substitution, and further improve electrification and energy efficiency. The energy transition also entails raising power and renewable energy utilisation in buildings, transportation, and industry; building greener and lower-carbon cities, transportation systems, and industries; and popularising clean and renewable heat. This will result in better coordination of energy production and consumption among population, resources, and the environment.

To analyse and forecast changes in future final energy demand accurately, CREO 18 has developed the End-use Energy Demand Model (CNREC END-USE) within the overall accounting framework under LEAP (Long-range Energy Alternatives Planning) software. The CNREC END-USE model analyses the final energy demand in 2050 by a bottom-up approach and end-to-upstream analyses. The bottom-up approach in the model sets assumptions in details in different sectors and subsectors individually based on existing statistical or forecasted data, which is then summarised to larger sectors and the entire energy system. Since the parametric assumption, analysis method and analytical focus of different sectors vary due to the difference in the two scenarios, the model will make specific analyses on particular problems in following sectors.

6.3 Energy consumption revolution in the Stated Policies scenario

The Stated Policies scenario anticipates policies will promote advanced energy-saving technologies, efficient end-use energy devices, and demand side response technology and they will enter into widespread use. In this scenario, China's energy demand growth slows and demand peaks at 3,385 Mtce by 2028, declines to 3,187 Mtce by 2040, and falls to 2,907 Mtce by 2050. Along with the microeconomic and macroeconomic changes, China's economic growth will continue while energy demand becomes more structurally balanced. Energy growth will center on transportation and the residential and commercial building sectors. By 2050, under this scenario China's final energy demand by sector will shift from 60% industry, 16% transportation, and 21% buildings to 42% industry,24% transport, and 28% buildings.

Figure 6-3: Final energy demand in main fields of China in 2016

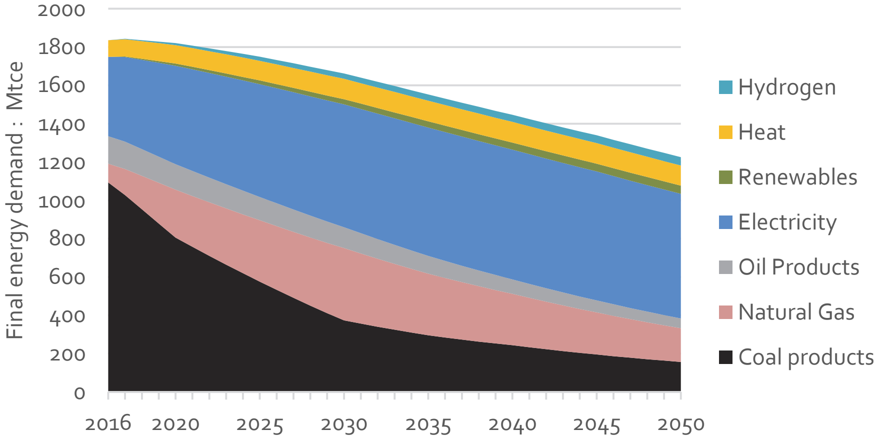


Industrial sector

Industry is the cornerstone of China's economy and also its largest final energy consumption sector. According to the China Energy Statistical Yearbook, in 2016 China's industrial sector consumed 2.097 billion tce[127]. This accounted for 59% of the total final energy consumption, of which four major energy-intensive industries—steel, chemicals, non-metallic and nonferrous metals—represented over three-fourths.

The Stated Policies scenario projects that by 2050, industrial sector final energy demand will fall to 1226 Mtce, 33% below the 2016. Heavy industries decline as a proportion of industrial energy consumption to 52%. The boom of high-value-added products and high-end manufacturing leads to a more balanced pattern of final energy demand: the total share of electricity and electricity-based hydrogen 23% to 57%; natural gas grows from 4% to 14%; district heating grows from 5% to 9%; direct renewables together grow to 4%. The share of coal and coal products (including coking coal) in industial final energy demand declines from 60% to 13%, while oil products decline from 8% to 4%.

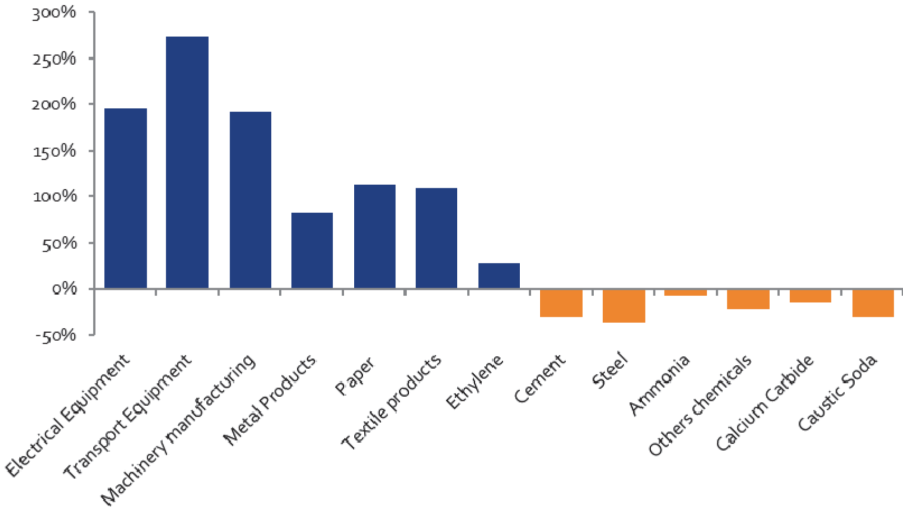
Figure 6-4: The industrial energy demand in the Stated Policies scenario



Inter-sectoral rebalancing and energy efficiency reduce industrial energy demand

As China has reached the middle or late stage of industrialisation, many heavy industries have reached their peak and experienced overcapacity. In conjunction with rising production costs, rapid development of smart and automation technologies, China's higher-value manufacturing industry is becoming globally competitive, and the country's trade relations are transforming from a position of low-end manufacturing supply chains towards fully integrated domestic supply chains for a full range of consumer or industrial products. Rebalancing within the industrial sector means heavy industry will decline, urban industries such as food manufacturing and clothing will continue to grow, and low-energy intensity and high-value services will expand.

Figure 6-5: Output changes of major industrial products between 2016 and 2050

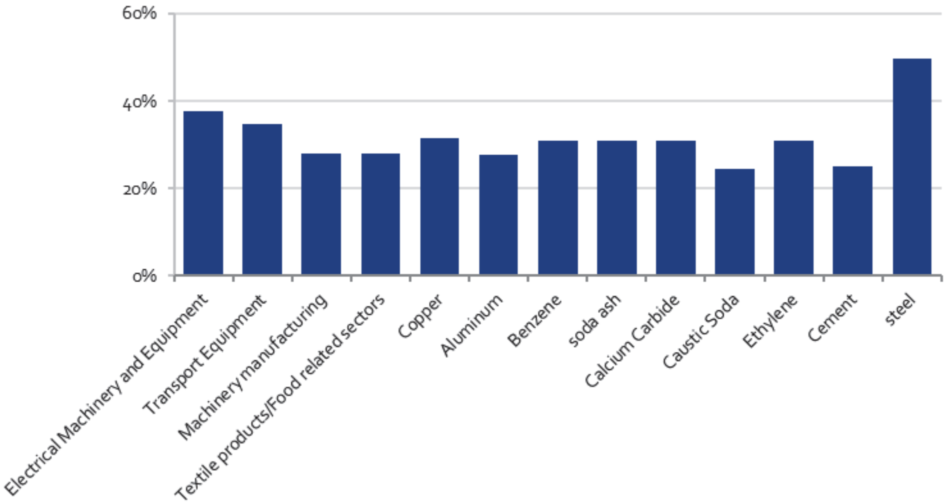


Technology and innovation are the primary drivers of improved energy efficiency. As for industry, the determining reason for the high energy consumption is the inefficiencies brought by outdated technology and low-efficiency equipment. The following fields will see particularly rapid gains in energy efficiency technology:

- Energy-intensive equipment, such as industrial boilers, furnaces, motor systems, distribution transformers.
- Technology integration and process optimization of energy-intensive systems..
- Recycling of waste heat and other residual energy, and urban residential heating from low-grade waste heat from steel and chemical industries.
- Intelligent and digitalised manufacturing.

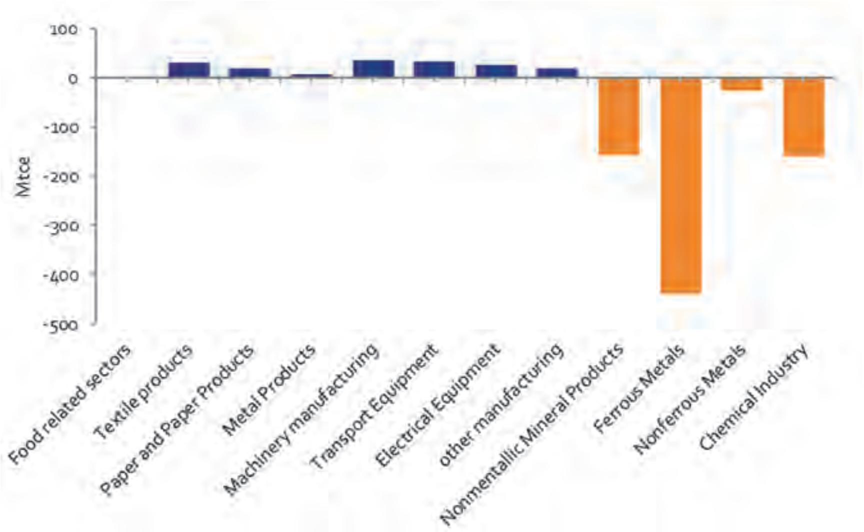
The Stated Policies scenario projects that by 2030 China's industrial energy efficiency will catch up with that of OECD countries, and by 2050 the energy intensity in steel, cement, nonferrous metals, chemicals, machinery, textiles, transportation equipment, and electronics manufacturing will improve substantially relative to 2016, as shown below.

Figure 6-6: Energy efficiency improvements by industrial sector in 2050 compared with 2016



Under the dual influence of inter-sectoral rebalancing together with energy efficiency improvement, the heavy industrial energy demand will drop sharply, fully offsetting the demand growth in light- or service-oriented industrial branches. China's industrial final energy demand will enter a stage of negative growth.

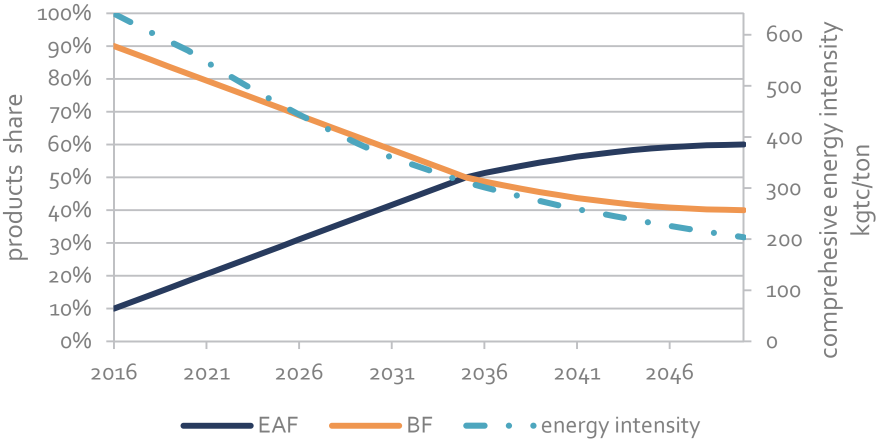
Figure 6-7: final energy demand changes of different industrial branches between 2016 and 2050



Electrified steel-making and green cement production enable coal phase-out

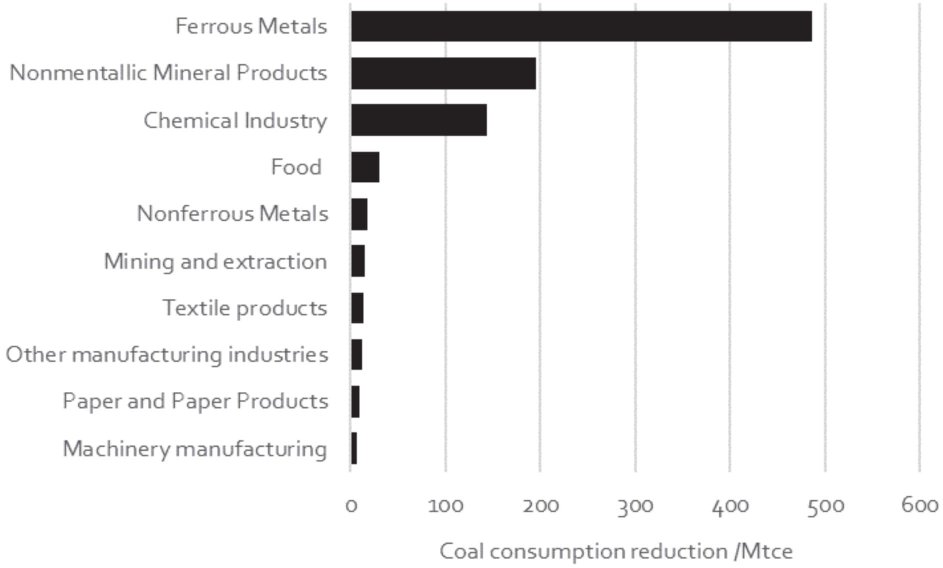
Currently, production of steel, cement, and chemicals consumes most of the coal in industry, accounting for 52%, 19%, 16%, respectively. In steel making, most of coal is consumed by blast furnaces. Steel from electric arc furnaces (EAF) is cleaner and more efficient, its current application in China's steelmaking is relatively low, and EAF steel contribute only 10% of steel production. China' steel sector strategy is to complete the scrap recycling system, accelerate electrification, and phase out BF-BOF (blast furnaces to basic oxygen furnaces) as soon as possible. The Stated Policies scenario projects 45% of retired steel can be collected for reuse. EAF steel produced by scrap could account for 60% of steel production in 2050.

Figure 6-8: The production share of different steel technologies in stated policies scenario



In both scenarios, cement also undergoes a green and low-carbon transition. As China's infrastructure investment boom subsides, and slower urbanisation leads to lower new building construction activity, lower concrete demand drives down demand for cement and concrete. The Stated Policies scenario projects China's cement production to fall 32% by 2050 from the current level. Meanwhile, the following measures are expected to be adopted: further clinker substution by alternative materials; promote high belite cement which needs lower peak temprature and less clinker; new powder technology without grinding aids; process control optimization of rotary kiln line; enhance the recovery of waste heat; use refuse-derived fuel (RDF) and electric rotaory kilns to phase out the rest of coal. These green decarbonisation measures remove 937 Mtce of coal from industry fuel demand by 2050. Steel-making accounts for the biggest share in coal reductions of 52%, followed by the cement, around 21%.

Figure 6-9. 2016-2050 coal reduction in industrial sectors in the Stated Policies scenario



Hydrogen enables to further intake renewable electricity

Both scenarios assume increasing uptake of hydrogen for industry. With the future cost reductions of renewables, using wind and solar for water electrolysis for hydrogen or manufacturing hydrogen-rich chemicals would help lower industrial emissions while soaking up wind and solar at times of surplus output. Hydrogen could be used as the reducing agent to replace coking coal for crude steel, and also to produce ammmonia, replacing current coal-based synthetic ammoica production technologies. in The deployment of hydrogen in industry in the two CREO scenarios mirrors that of recent global energy scenarios developed by IEA and Irena.128 In the Stated Policies scenario, in the industrial sector hydrogen will use 44 Mtce electricity (358 TWh) by 2050, 4% of total projected 2050 industrial demand.

Electrified industry and hydrogen-rich fuels

On the expectation of ever-decreasing electricity costs from abundant solar and wind, newer options for electrifying the industry are emerging:

Electric heat pumps produce low temperature heat, which represents about half the energy demand for heat by industries, with an efficiency of 300%-700%. Mechanical vapour recompression avoids losses of latent heat and provide steam and provides a coefficients of performance greater than 10. Electric resistances are less efficient but also less costly. They can thus bypass the use of fossil fuels at times of excess variable renewables and low electricity costs, a benefit that heat storage can extend.

Electro-magnetic heating technologies, including infrared, dielectric and induction, generate heat within the material target rapidly with an efficiency twice more of direct resistance heating by fossil fuel. Infrared heating could be used in various industries for curing, gluing, laminating, melting, shrinking, soldering and tempering; induction for metal processing such as melting, hardening, tempering, brazing, welding and pre-heating; dielectric heating, based on microwaves and radio frequency, is particularly effective at drying poor heat-conducting materials such as bricks and wood. These technologies also allow for more rapid and more controllable processing, reducing material wastage from contact with combustion gases, and improving workers' safety and comfort.

Besides electric resistance, electric arc and plasma arc furnaces, ovens and kilns can replace their fossil-fueled counterparts. Some manufacturers intend to use plasma furnaces for processing cement, considerably reducing energy-related polluting emissions.

Innovative uses of hydrogen in industry would go along these developments. Green hydrogen would result from water electrolysis using renewable electricity or methane splitting in plasma furnaces. Steel today is largely produced in blast furnaces and basic oxygen furnaces. Green electrolytic hydrogen could reduce iron ores following the alternative, currently natural gas-based direct iron reduction route, prior to melting in electric arc furnaces together with scrap steel.

Beyond the role as an industrial feedstock or reactant, green hydrogen can be used in transportation for fuel cells or for power generation as a substitute to fossil fuels. Ammonia can be used as a hydrogen-rich fuel that contains no carbon, while synthetic methane, methanol and a great variety of hydrocarbons can be produced from green hydrogen and carbon, with benefits from the climate that differ according to the origin or that carbon. Wherever possible, however, direct electrification is likely to be more efficient than the use of hydrogen or hydrogen-rich fuels, which would likely find their greatest justification in long range transportation such as maritime or aviation, or in applications requiring long duration storage, and in helping harness vast stranded renewable energy resources remote from large consumption centers.

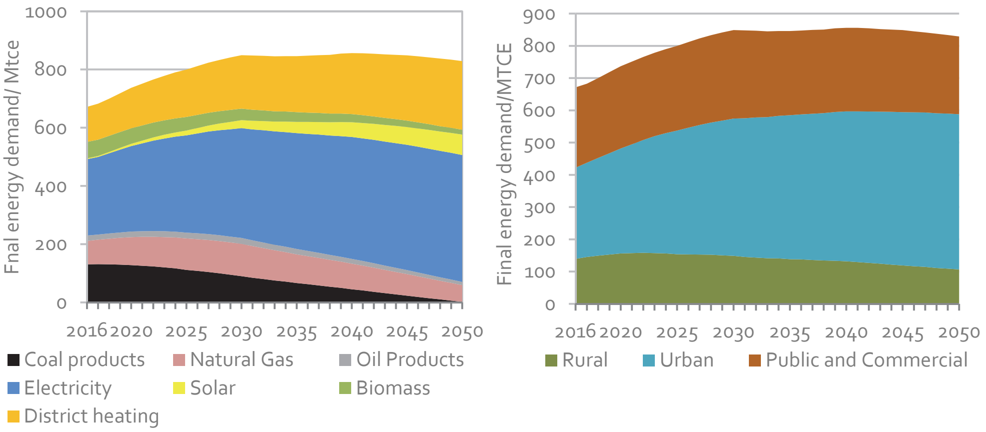
Buildings sector

The buildings and buildings construction sectors combined are responsible for 36% of global final energy consumption and nearly 40% of the total direct and indirect CO_2 emissions.[129] In contrast, China energy consumption in buildings is about 671 Mtce, or only 21% of the final energy. Services such as cooling and heating are not fully met in economically underdeveloped areas. With continuing economic growth, urbanization, and increasing attention to indoor living conditions, China's energy demand for buildings will grow, reaching a peak around 2030 at about 849 Mtce, 26% above today's level, then almost plateau and decline slightly to 2050.

The CREO scenarios project that building energy fuel mix will also change. Of 828 Mtce in final energy consumed by buildings in 2050, electricity takes up 53% (up 14 percentage points from present), district heating takes up 28% (11 percentage points higher), renewables such as solar and biomass take up 11% (2 percentage points higher than today). Utilisation of renewables shifts from low-efficient biomass stoves to cleaner sources. Coal for building energy falls almost to zero in both scenarios.

Energy demand will grow in public, commercial, and urban residential buildings, while urbanisation means energy demand in rural buildings will continue to drop, as shown below. Final energy demand in the building sector will grow rapidly through 2030, then slow due to building energy saving measures and the promotion and implementation of passive building technology.

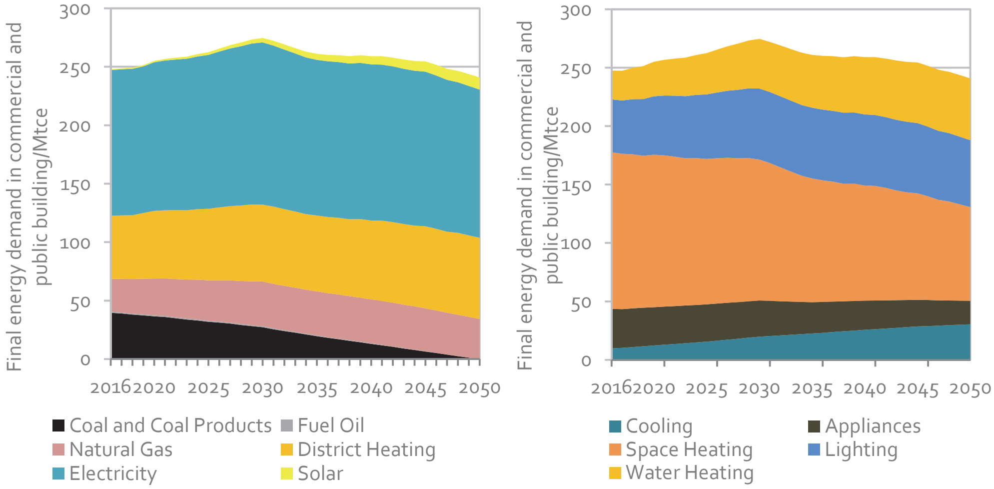
Figure 6-10: Future energy demand in the building sector in Stated Policies scenario



Features of energy demand in different building types

Similarly, the energy demand of public and commercial buildings will increase first and then decrease gradually. In the short term, due to the industrial transformation, more workers entering the tertiary industry, the energy demand of public and commercial buildings will increase to 275 Mtce by 2030, 11% higher than 2016. In the long term, public buildings will play a leading role in energy efficiency improvement and adopt a advanced energy-saving technologies. By 2050, their energy demand will fall to 241 Mtce. The two major fuels in public and commercial buildings are electricity and district heating, mainly for central air conditioning systems (heat pumps) and space heating, of which electricity accounts for 53% and heat accounts for 29%. The proportion of natural gas accounts for 14% by 2050, also mainly for space heating. Renewable energy is mainly based on solar energy, accounting for 4% in 2050.

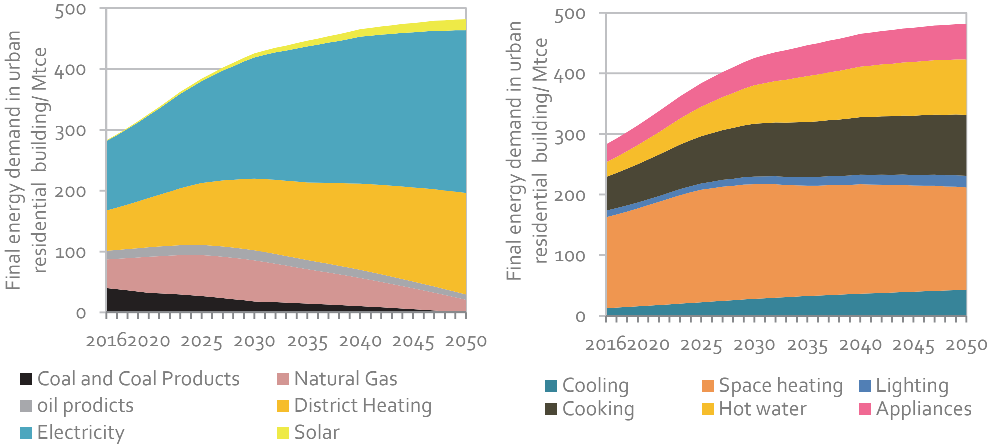
Figure 6-11: Energy demand in public and commercial buildings in Stated Policies scenario



Urban residential buildings energy demand mainly goes to space heating, cooling, domestic hot water, cooking, lighting, and household appliances. Currently space heating and cooking take the biggest share. The main fuel is electricity, and district heating is only used in northern China. Renewable energy is mainly solar hot water, and the current utilisation rate is still low. It is estimated the energy demand of urban residential buildings will continue to grow from 283 Mtce in 2016 to 481 Mtce in 2050, driven by demand for modern amenities and services such as heating, refrigeration, ventilation, lighting, and household appliances. In 2050, our scenarios project that energy demand in urban residential buildings will be met almost entirely from clean energy, mainly electricity and district heating, with electricity accounting for 55% and district heating accounting for 35%. Natural gas for buildings grows rapidly, reaching 68 Mtce in 2028 before leveling off in our projection. Gas is mainly used for clean heating, and then gradually replaced by electric heating and central heating.

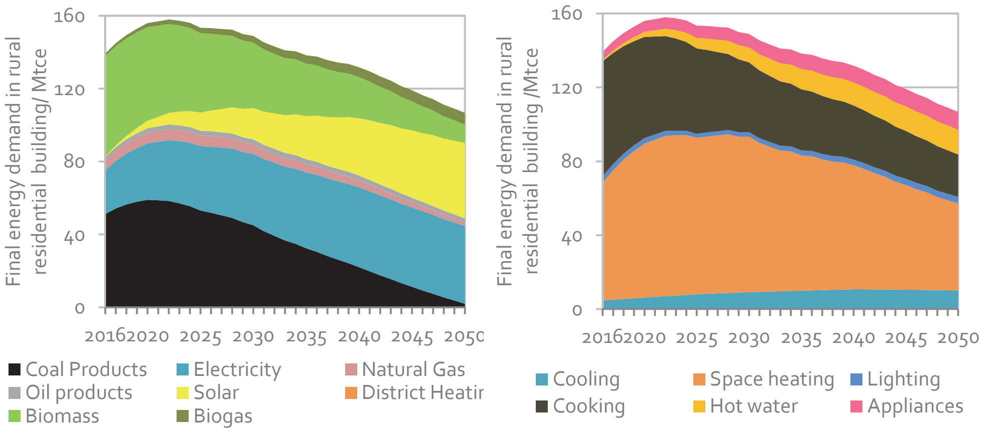
The demand for cooking and domestic hot water will also increase in urban buildings. The increasing demand for space heating will be largely offset by energy-saving actions and energy efficiency improvement. The use of home appliances will further increase. At the same time, compared with OECD countries, the energy demand for cooling and ventilation appliances in China's residential buildings will also increase relatively rapidly in the future.

Figure 6-12: Future energy demand in urban residential buildings in Stated Policies scenario



The current fuesl used in rural areas are loose coal and biomass, providing cooking energy and space heating. But the use of such inefficient non-commodity energy is projected to decline with the development of rural economies. We expect high-efficiency solar utilization will provide for space heating and domestic hot water. Electricity and electric heat pumps will also increase in rural areas. In contrast, the Stated Policy scenario anticipates rural building coal use will decline to almost zero by 2050.

Figure 6-13: Future energy demand in rural residential buildings in Stated Policies scenario



Rural residential buildings energy demand increase sharply to 157 Mtce in 2020, 13% higher than 2016, then starts to drop due to energy saving measures and also passive rural buildings, in 2050 it drops to 106 Mtce. By 2050, 94% of rural energy needs will be provided by clean energy, of which electricity will account for 40%, solar for 39%, and biomass (including agricultural and forestry residues and biogas) for 15%. Among all the building services, the share of space heating and cooking is still high, 44% and 21% respectively. The proportion of domestic hot water has increased significantly, from 0.5% in 2016 to 13%

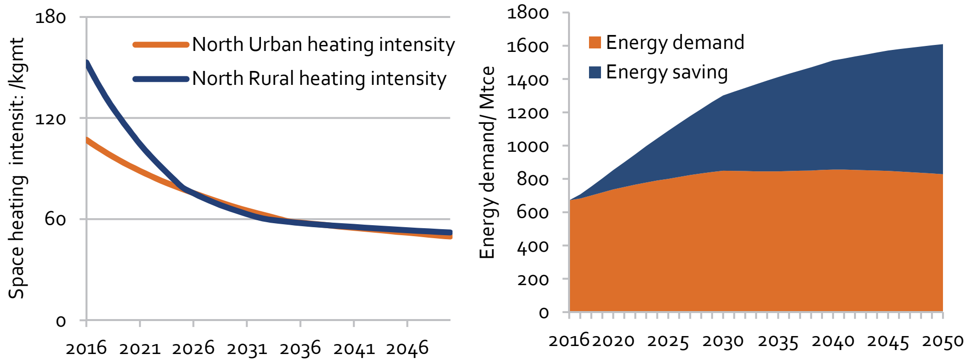
by 2050, and cooling and appliances account for 9% respectively. Lightning accounts for 3%.

Implementation of energy saving measures and passive buildings is the key action

Energy saving is especially important for the building sector in China. In rural areas, buildings are not designed with energy-efficiency in mind; in cities, decades-old residential buildings consume two to three times more energy than comparably-sized European buildings. Meanwhile, due to the hidden subsidies for residential energy use, the prices of energy services in buildings do not fully reflect their costs, which results in a general lack energy-saving awareness and high energy waste. To a large extent, energy waste can be reduced through simple retrofits or design measures, such as improving building materials, upgrading insulation of roofs, doors and windows, increasing airtightness of buildings to minimize the need for heating and cooling, and installing better building controls and heat meters.

In recent years, China has implemented a host of policies to promote building energy efficiency, including mandatory building energy codes for new buildings to raise the compulsory standards for energy performance. Central and local governments have adopted plans for renovation of existing buildings. Pilot programs based on green building ratings and passive buildings have been introduced in many areas of the country. Following this trend, we expect China to accelerate the retrofit of existing buildings, increase building energy efficiency standards, and promote passive building technology. We project significant improvements in average building energy intensity by 2030.

Figure 6-14: Future heating intensity, energy demand n and energy saving gains



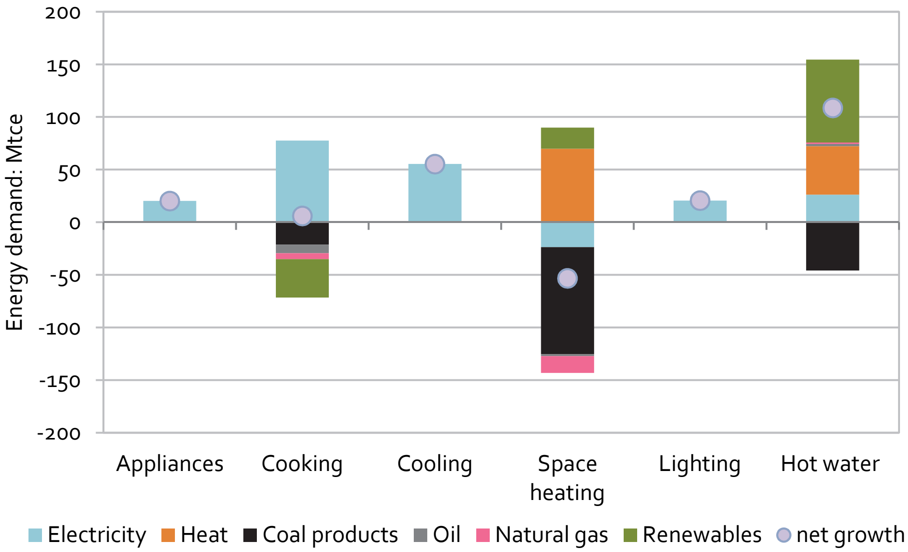
The Stated Policy scenario anticipates that by 2030, 100% of the existing urban residential building will be retrofitted to meet energy saving code 75, and by 2035, 100% of the existing public and commercial buildings will be retrofitted to meet energy saving code 75. 100% of newly-built urban residential buildings and public and commercial buildings will be implemented under energy savings code 85, and by 2040, 100% of existing rural building will be retrofitted to meet energy savings code 75. We anticipate that by 2050 the share of passive building will gradually grow to 80% for newly-built urban residential buildings, and

100% in newly-built public and commercial buildings. With all these actions, the buildings sector will save about 782 Mtce compared to the situation without the energy-saving measures.

Clean energies meet all of building energy demand growth

By 2050, the building net energy demand growth is about 157 Mtce. Electricity, district heating, and renewables contribute the entire growth in final energy demand. The growth in household appliances and office equipment, cooling and lightning are covered by electricity alone. In cooking, apparent energy growth is almost zero, but electricity replaces most other cooking fuels. Water heating shows the most growth, growing by a factor of 3.3 times today's level, fueled by all three clean energies, in which renewable energy is the biggest share. Heating demand decreases with improved efficiency, and more renewables and district heating are employed to replace electricity and natural gas.

Figure 6-15: Future energy growth and fuel mix in different building services



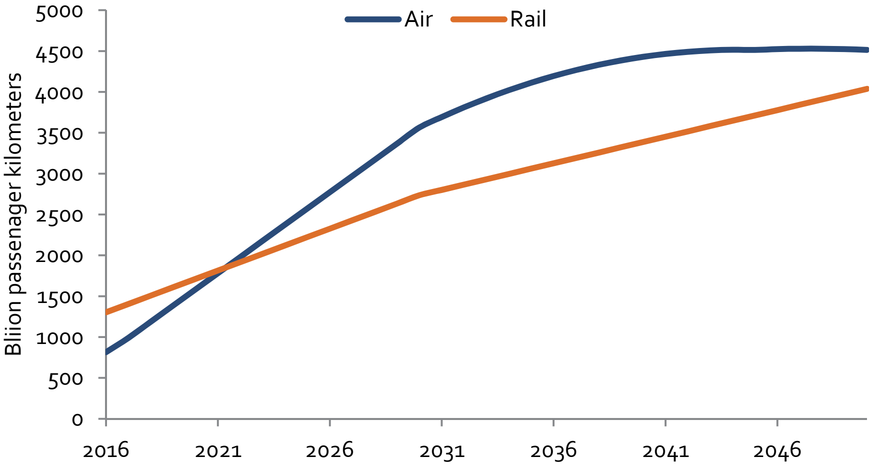
Transport sector

Energy consumption in transport has grown rapidly in China since 2000, when China began to rapidly grow 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. For a decade China has been the largest car market in the world, with annual sales 60% higher than the second-largest car market, the U.S. The CREO scenarios anticipate this trend will continue as China's travel patterns converge with European levels by 2050, while vehicle ownership similarly reaches European current levels by 2050. Public transport in China will be larger than Europe, influenced by high urban densities and long travel distances between cities. Due to the expansion of public transport and urbanisation, we project vehicle ownership will peak by 2030. Public transportation, especially subways, high-speed trains, and air travel are not projected to peak before 2050.

A controlled growth of energy demand

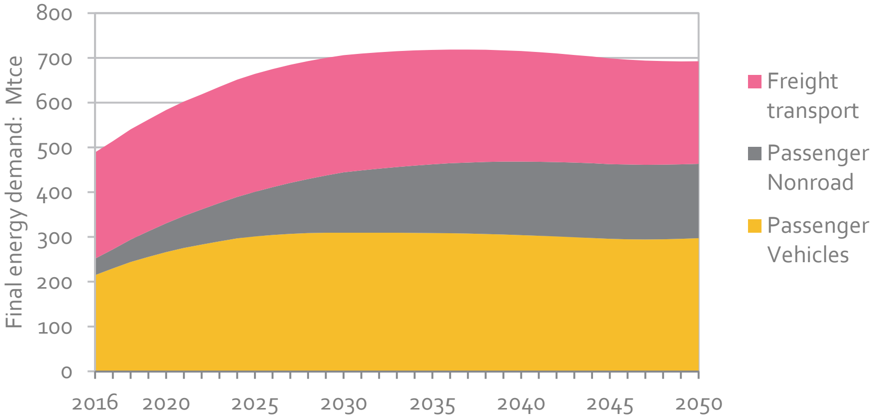
Non-road transportation, especially the passenger flights, is projected to increase rapidly throughout the forecast period. With higher affluence, we anticipate the Chinese population will travel as much as North Americans and Europeans today, both domestically and internationally. Compared with the railway, the potential of air travel is even larger in China driven by the growing demand for long-distance transport. Thus, the scenarios expect air travel demand per capita to reach the current level in Europe by 2050.

Figure 6-16: Future growth in China air and rail travel



Although we anticipate transport energy demand will continue to grow as well, for several reasons it will grow more slowly than growth in car ownership, air travel, or other transport would imply. China has strict policies limiting the sales of internal combustion vehicles in certain cities, and China has invested heavily in electric rail and urban public transport. For several years running, China continues to lead the world in electrifying and decarbonising the transport sector. Given these measures, we forecast China's transport sector will experience controlled energy demand growth and reach a plateau between 2030 to 2043, with energy demand roughly 40% higher than the 2017 level, then slightly decline. Freight transport still accounts for a considerable share of the total transportation energy demand. Even with impressive vehicle ownership growth, we project that energy demand of passenger vehicles will change little due to the shift to more efficient vehicles.

Figure 6-17: Future energy demand in the transportation sector in Stated Policies scenario



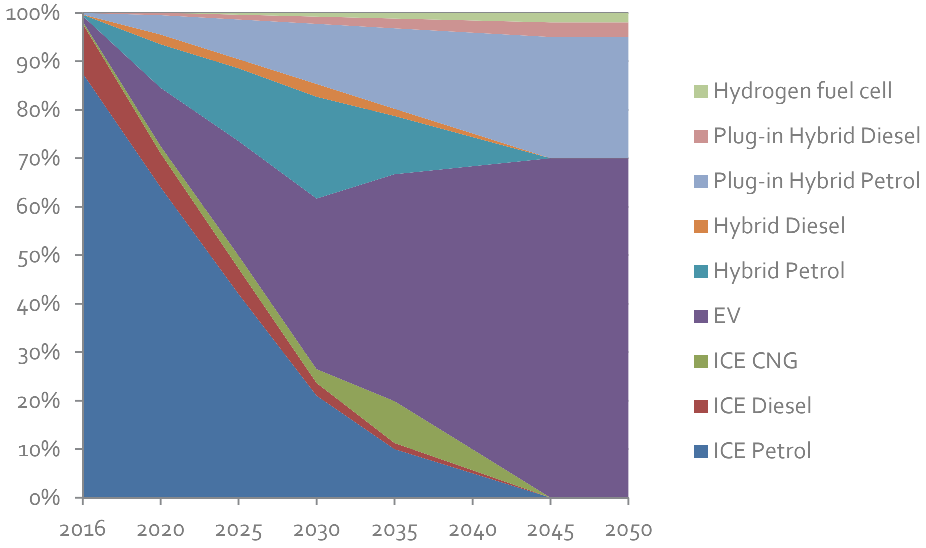
Non-road transportation will undergo the greatest development. Flights are projected to be the largest fossil fuel consuming transport sector by 2050, due to its high growth. By 2050, flights are responsible for half (50%) of the fossil fuel consumption in China. The energy consumption of flights will dominate the non-road transport sector while the train and shipping energy use will grow at a steady rate. If there were no growth of flights compared to the 2016 level, China's transport sectors would consume 35% less fossil fuel compared to 2016.

Dramatic electrification in road transportation

Among all the sectors, transportation will experience the greatest technology transition toward electrification, mainly for on-road vehicles, including both cars and trucks. Different provinces and cities in China have some of the world's most progressive and favourable policies for the adoption of new energy vehicles, especially battery electric vehicles (BEVs). China already accounts for the majority of BEV sales globally. We project EV adoption trends continue to accelerate, such that by 2030 BEV sales constitute 35% of total passenger vehicle sales. We project that by 2037 EVs will surpass combustion engine vehicles in annual sales, and by 2050, BEVs account for 70% of new passenger vehicle sales.

New energy vehicles, which include BEVs, fuel cell vehicles, and plug-in hybrid gasoline vehicles, achieve 50% sales saturation by 2030. We expect that by 2045 China will ban sales of conventional internal combustion engine vehicle, after which 100% of sales are new energy vehicles. Besides these, 70% are BEV, 25% of the remainder are plug-in hybrid gasoline and plug-in hybrid diesel and hydrogen fuel cells are 3% and 2%, respectively.

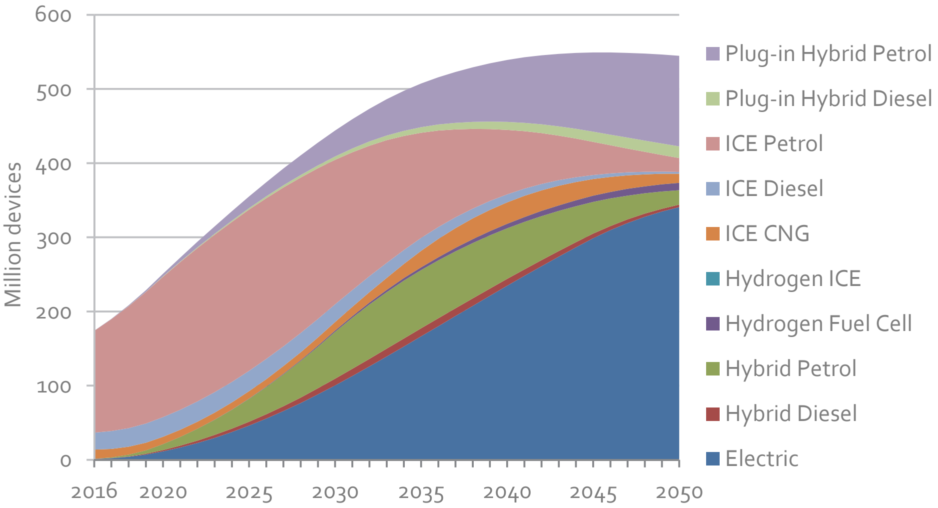
Figure 6-18: China projected annual passenger vehicle sales in Stated Policies scenario



Despite the improvements in end-use efficiency that comes with transport electrification, China does not see major changes in the total final energy consumption for vehicles, due the rise in ownership and use of passenger vehicles. By 2050, we project that over 46 million passenger vehicles are sold per year, 185% above the 2016 sales figures. The total passenger vehicle stock in China reaches 544 million vehicles in 2050, up from 173 million in 2016.

Vehicle lifetimes also affect energy consumption patterns, given the lag in retirement of older vintage, less-efficient vehicles. The Stated Policies scenario estimates that new energy vehicles in China will represent 32% of the passenger vehicle stock in 2030 and 88% in 2050. The vast majority of the New Energy Vehicles (NEVs) in 2030 are battery-electric vehicles (BEVs), accounting for 23% of the total stock. By 2050, we project other NEV technologies will have gained a larger share in the NEV category, but BEVs are the dominant overall technology in Chinese passenger vehicle stock, accounting for 61% of all passenger vehicles by 2050. BEVs become the dominant technology among passenger vehicles by 2044.

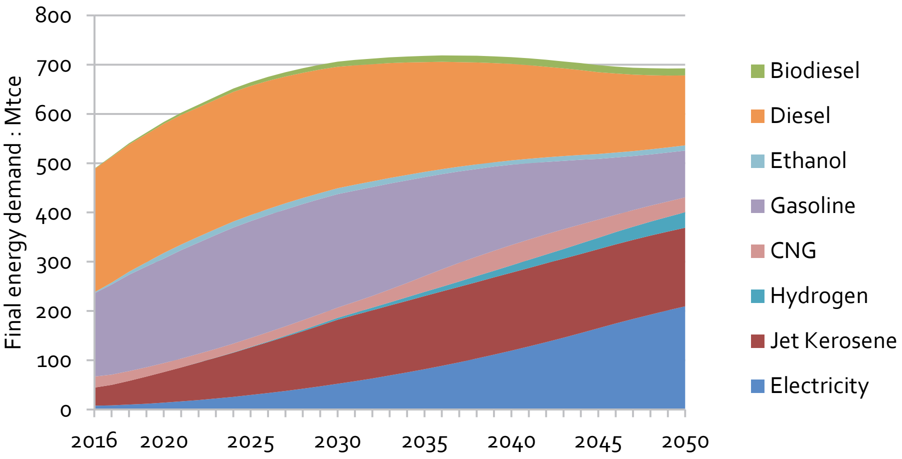
Figure 6-19: Future vehicle stock for the passenger vehicles in Stated Policies scenario



More diverse fuel mix

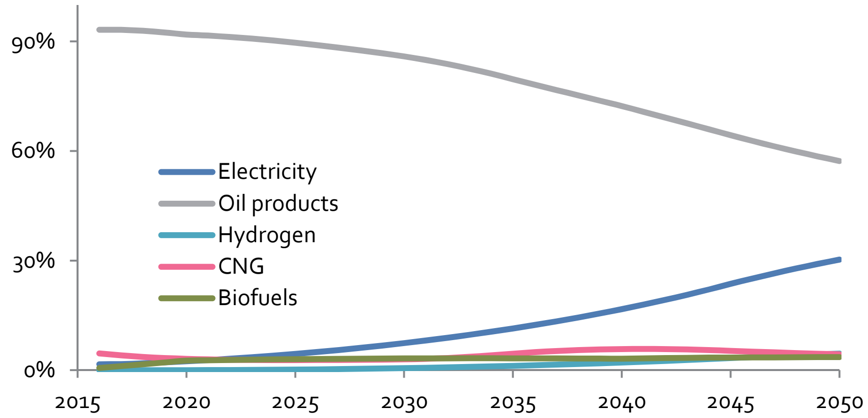
The transportation sector relies heavily on oil products, which meet 93% of sector demand today. With the rapid transition towards new energy vehicle technologies, and the expansion of electric non-road transport, China's dependence on fossil fuel is projected to peak around 627 Mtce early in 2029, 25% above the 2017 level. After that, the main trend will be the substitution of petroleum products with electric drive and other alternative fuels. Our projection anticipates that by 2050, China will only consume 85% as much fossil fuel for transport as in 2017. Most transport fossil fuel use will come from oil products, with jet fuel as the biggest share.

Figure 6-20: Future energy mix in the transportation sector in Stated Policies scenario



Rapid electrification is the main driver for reducing China's dependence on oil in the transport sector. By 2050, electrification rate in transportation increases from 1.62% to 30%, while share of oil products declines from 93% to 57%. Hydrogen and biofuels also start to make a contribution, with hydrogen taking 4.6% of the fuel mix and biofuels 3.6% by 2050.

Figure 6-21: Future fuel shares in transportation energy demand of Stated Policies scenario



6.4 Additional measures needed to achieve Below 2 °C scenario

However, according to our analysis, even a successful implementation of the Stated Policies Scenario is insufficient to comply with this emissions budget required by Paris Agreement for a below 2 °C future. More effective and ambitious national actions are needed in demand side reform to meet Paris Agreement-compatible emissions levels. On the demand side, this implies China will need to phase out fossil fuels at a faster pace and meanwhile accelerate the electrification in transportation, industry, and other sectors.

Industrial sector

Light services employ biomass and electricity to further replace fossil fuels to provide thermal energy. Electricity substitute larger amounts of coal use in industry thanks to heat pumps, mechanical recompression of vapour, direct resistance and electromagnetic technologies such as micro-waves and radio frequency, radiant infra-red heat, ultra-violet, and induction, for a wide range of industrial processes. Furthermore, large electric arc and plasma furnaces and kilns replace fossil fuels in manufacturing cement and other non-metallic minerals to a larger extent.

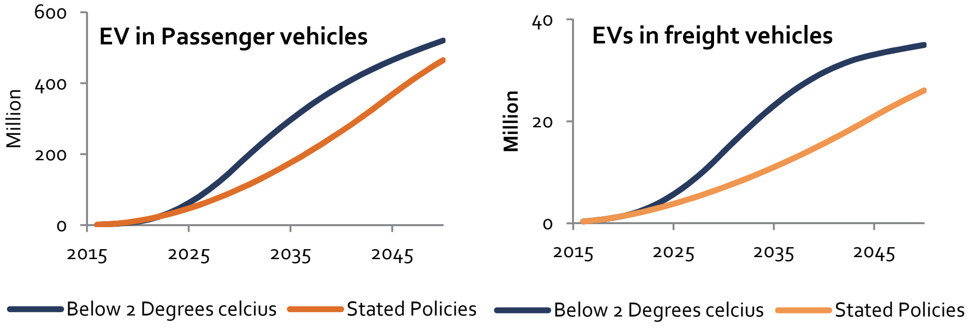
Industrial hydrogen is produced on a larger scale in electrolysers to further curb coal consumption in the production of hydrogen for ammonia making, and in methanol production. Some hydrogen is also used to reduce iron ore following the direct iron reduction route, followed by melting in EAF together with scrap steel. In Below 2 °C scenario the EAF share is further increase to 75%, with a more efficient scrap recycling system to guarantee the collectable retired steel rate is 60%.

Transportation sector

Compared to the Stated Policies scenario, the Below 2 °C projects that at least 64.5 million more EVs are needed in 2050 for passenger and freight transportation. The share of electricity in the total final energy use should reach at least 53%, 5% higher than in Stated Policies scenario. A faster shift from air travel to high-speed railway also contributes to lower emissions.

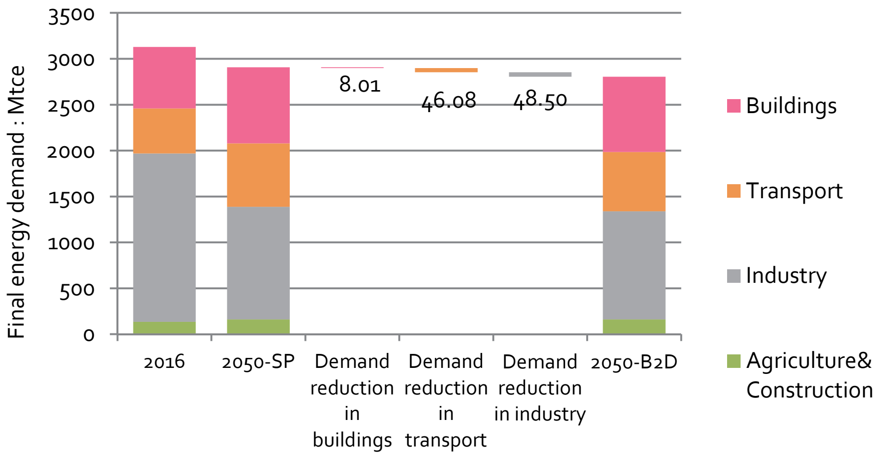
It is estimated that by 2050, there will be 510 million electric vehicles on the road, accounting for 95% of the total car stock, which not only intake large amounts of variable renewable energy, but also contribute their batteries to auxiliary services such as peak regulation and frequency modulation.

Figure 6-22: EV stock in two scenarios



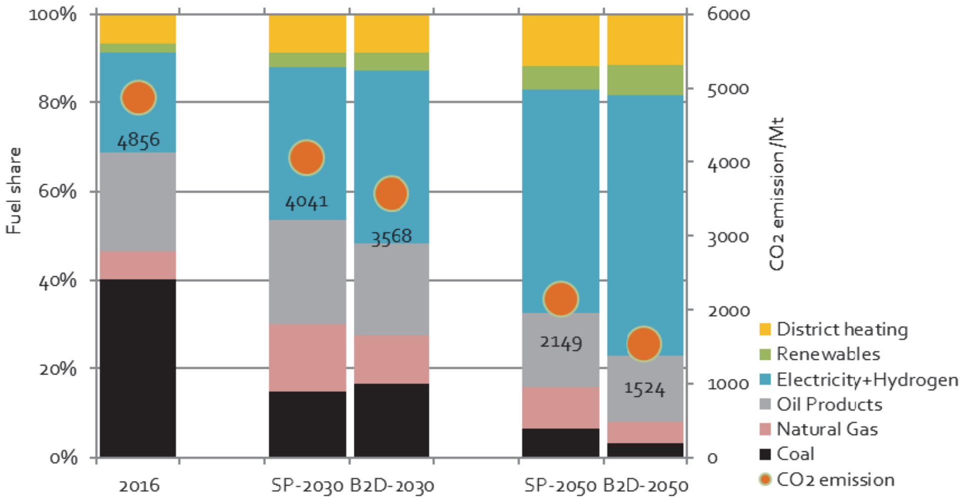
In the Below 2 °C scenario, China's final energy demand in 2050 is 2804 Mtce, 103 Mtce less than in the Stated Policies scenario. Though this difference may appear minor, the real change is in fuel mix.

Figure 6-23: Final energy demand reduction in Below 2 °C scenario



In the Below 2 °C scenario, the fuel mix shifts in several respects versus the Stated Policies scenario. The 2050 combined share of electricity and hydrogen further increases by 9% in the Below 2 °C scenario compared with Stated Policies; fossil fuels are replaced by clean and net zero carbon energies, with the combined fossil fuel share falling from 33% in Stated Policies to 23% in Below 2. In 2050, CO_2 emissions reach 1252 Mton in the Below 2 °C scenario, a difference of 625 Mton relative to the Stated Policies scenario.

Figure 6-24: Fuel shares and carbon emissions in two scenarios

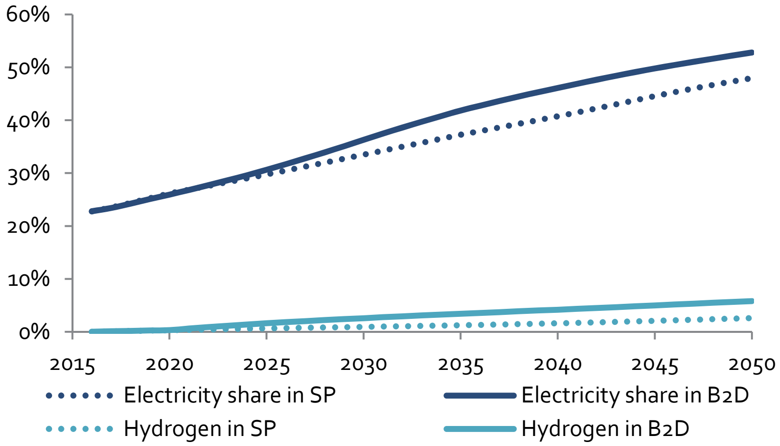


6.5 The role of electricity in the two scenarios

Electrification is the core of the entire energy revolution. It not only increases energy end-use efficiency in demand side, but also creates a huge market demand for electricity, which allows more integration of renewable sources into the grid. Meanwhile, a potential power supply shortfall created by replacing direct fossil fuel combustion with electricity will pressure the energy supply side to accelerate the clean energy transition. The Electricity First strategy in end-use service should start in the very early stage of this energy transition.

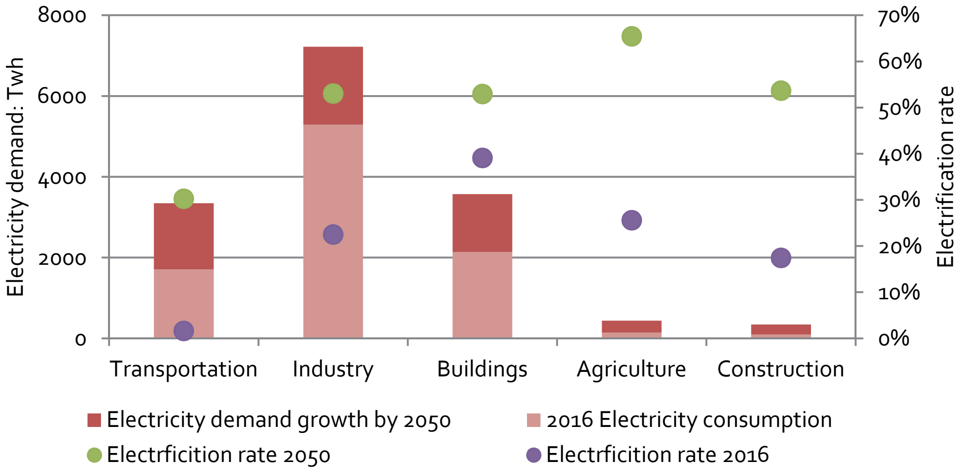
In Stated Policies scenario, from 2017 to 2050, the end-use electricity demand increases nearly two fold to 1,395 Mtce (11,355 TWh), and in the Below 2 degree scenario it is 1,481 Mtce (12,057 TWh). Hydrogen produced mainly from electricity consumes 102 Mtce (830 TWh) and 222 Mtce (1,808 TWh) in two scenarios, respectively, and also contributes 75 Mtce and 164 Mtce to final energy use. To further provide flexible electricity consumption and efficient energy storage, by 2050 district heating systems consume another 50 Mtce (486 TWh) and 75 Mtce (610 TWh) electricity in the two scenarios, respectively. The share of electricity in conjunction with hydrogen in the final energy use of China rises from 23% in 2016 to 51% in 2050 in stated policies scenario; in Below 2 degree scenario, it further goes up to 59%.

Figure 6-25: Shares of electricity and hydrogen in the final energy demand of two scenarios



Future electricity demand growth is driven by industry, transportation, and building sectors, together contributing 90% of the electricity demand growth. The electrification level of the three sectors will all increase substantially, as illustrated below. The transportation sector will experience the greatest technology transition toward electrification.

Figure 6-26: Electricity growth and electrification rate in the Stated Policies scenario

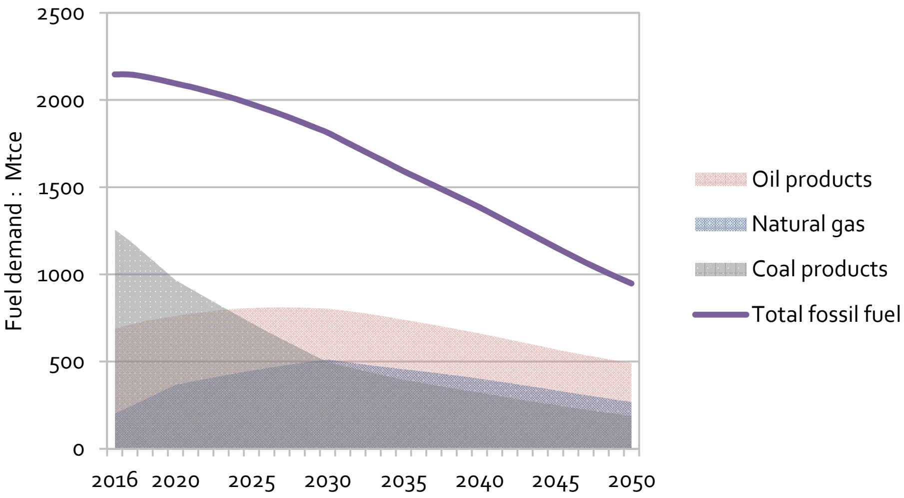


Further electrification of end-use sectors brings opportunities, but also some threats, to the integration of large shares of variable renewable energy sources. For example, smart charging of electric vehicles could help store excess energy at some times, while non-smart charging would increase demand peaks and ramp rates. Electrification of industry may bring in some unflexible loads; however, thermal uses may also be made more flexible with heat storage of simple heat management. A good example is provided by aluminium smelters. While these are usually very unflexible loads, introducing heat management in a German factory now allows the electric input to vary by plus or minus 30% around the nominal load.

6.6 The fossil fuel phase-out

What stands out in particular in the results of both the Stated Policies and the Below 2 °C scenarios is that demand for fossil fuels decreases from the very beginning of the forecast period. By 2050, in the Stated Policies scenario, fossil fuels decreases to 948 Mtce, 44% of today's level, with coal falling most dramatically, or 85% lower than today's consumption. Due to higher motorisation of road transportation, oil demand rises through 2027 to 811 Mtce, with 17% increase on today, then decreases to 491 Mtce in 2050, around 71% of today's level. Natural gas will experience an increase in the short term to meet heating demand in buildings and industry. Gas peaks in 2030 at around 523 Mtce, 2.6 times as much as today, then decreases to 269 Mtce in 2050, still 34% higher than today.

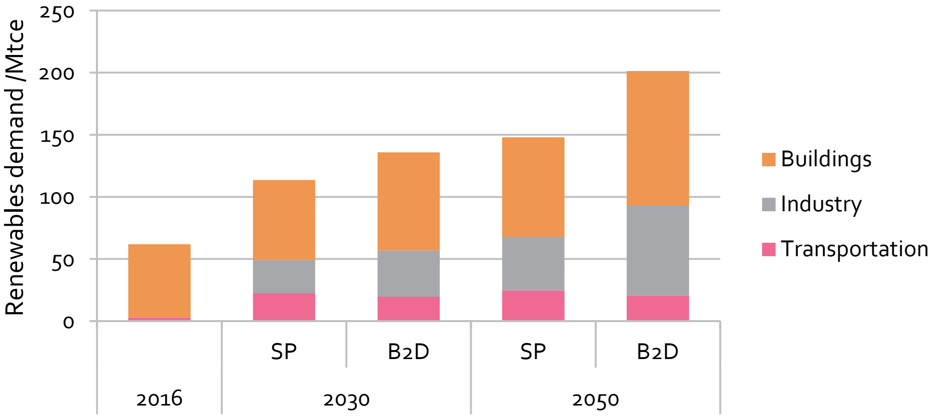
Figure 6-27: Future fossil fuel demand in Stated Policies scenario



6.7 The rise of renewables in the two scenarios

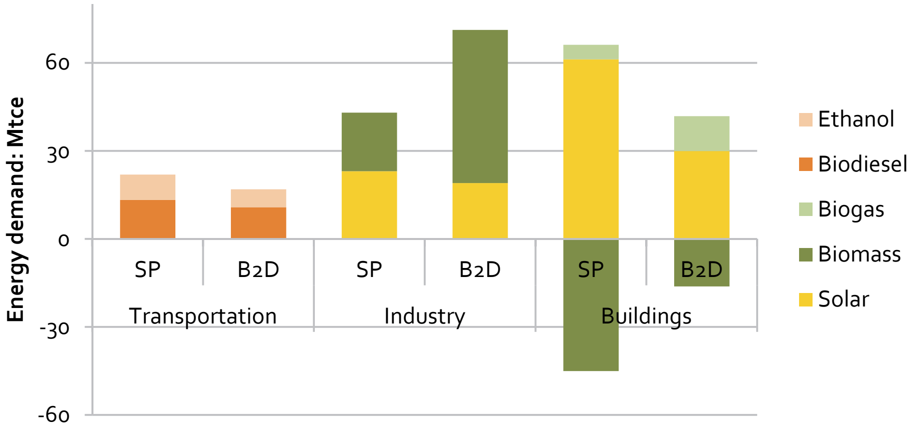
In both scenarios the demand for renewables in the end-use sectors increases steadily. In the Stated Policies scenario, the share of renewables increases to 5% by 2050, and in the Below 2 °C scenario it increases faster. Future growth centers on buildings and industry, which together contribute 83% of non-electricity renewables demand growth in the Stated Policies scenario, and 89% of non-electricity renewables demand growth in the Below 2 °C scenario.

Figure 6-28: Energy demand for renewables in the two scenarios



Demand for renewable energies differs by sectors under the two scenarios. In transport, biofuel provides a net increase of renewables, whereas in the Below °C scenario faster faster electrification implies lower biofuel consumption for transport. In industry, only biomass is used to replace more coal in boilers and kilns in the Below 2 °C scenario. In buildings, the reduction of biomass demand in stated policies scenario is due to policies that discourage low-efficiency biomass stoves, and encourage solar for space heating and hot water demand. In contrast, in the Below 2 °C scenario, more efficient household biomass boilers come into use, and overall building efficiency improvements associated with passive house and other building technology leads to a decrease of space heating demand and also less solar.

Figure 6-29: Renewable energy changes between 2016 in the two scenarios



7 Power sector outlook

7.1 Main messages on the power sector's transition

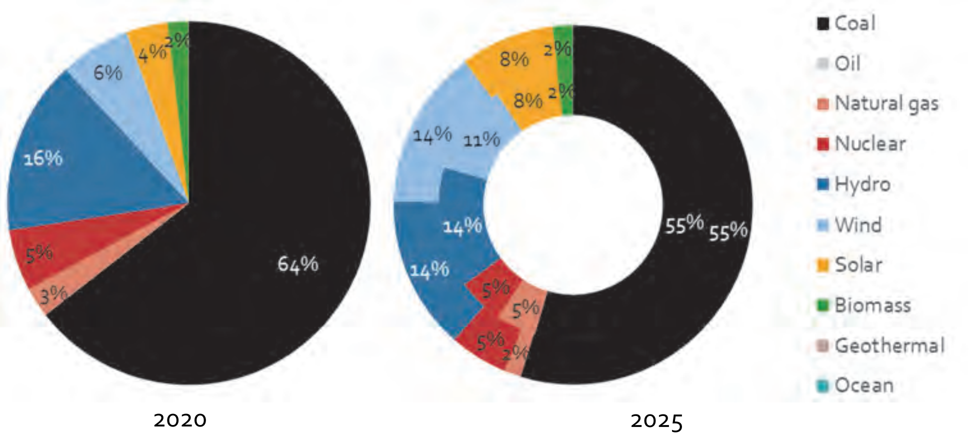
The power sector will be at the centre of meaningful energy transition in China. Energy consumption will be electrified, and electricity supply will be made clean, low-carbon, safe and efficient. Analysis of the two scenarios, particularly the quantitative results of the power sector modelling, generates insights on the role for, and development of, the power sector in the energy transition. These main messages are summarised below.

By 2020 China must be ready to accelerate wind and solar build-out

In the short term, China can reach 33% non-fossil power generation and 27-28% renewable power generation share by 2020. The average yearly deployment from 2018-2020 is 20 GW for wind and 33 GW for solar.

In the 14th Five-Year Plan period (2021 to 2025), China should set clear guidance for developing the power sector. In the Stated Policy scenario, the non-fossil electricity share is projected to increasing by at least 40%. To reach a pathway that is in accordance with the Paris agreement targets, the Below 2 °C Scenario projects non-fossil electricity should instead reach a 44% share by 2025.

Figure 7-1: Share of electricity generation in 2020 and 2025 – inner circle Stated Policies Scenario, outer circle Below 2°C scenario



With lower capital cost, the development of solar and wind power increase significantly between 2021 and 2025. On average, solar PV installation reach 70-85 GW per year while annual average wind installations grow to 40-70 GW in the two scenarios. New installations of solar PV and wind power will continue to grow in the following years and in the long-term wind and solar will form the core of the country's power industry.

Absence of firm power sector reform implementation would impede necessary RE scale-up. Implementation of power market reform, including spot markets with expanded access to renewables, utilisation of the full technical flexibility of the existing coal fleet, shifting renewable installation to low curtailment areas, and completion of planned transmission corridors should enable resolution of curtailment issues by 2020, which is in line with government targets. This is imperative for renewable development in the 14th Five-Year Plan period, and any worsening of curtailment would risk stalling renewable energy cost reductions and jeopardise China's long-term clean energy targets.

Investment in new power capacity should focus on development of RE projects, and on improving system flexibility to ensure efficient integration of renewables. We project 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. If the external costs of coal power plants are accounted for, investing in new renewable sources will be cheaper than continuing to operate existing coal plants.

In the short-term, it is unlikely that carbon prices will influence investments in the power sector. The power reforms and meaningful carbon price levels will take some time to implement. After 2020, the price of CO_2 should translate to a higher market value for renewables and a disincentive for fossil-fired generation. The auctioning of CO_2 allowances could finance accelerated investments in the energy transition.

A Beautiful China 2050 power system will have wind and solar at the core

In the long-term, wind and solar will be the cheapest and most abundant sources of electricity (in fact, when considering external costs, they likely already are), and the infrastructure and policies will be in place to ensure they can form the core of the power system. Ensuring efficient system integration of variable renewable energy is the primary power system development challenge.

Wind and solar power dominate future generation investments by default. To meet air quality and climate goals, coal use must peak in the short- or mid-term. The price of gas, and China's dependence on imported gas, limit development of this fuel, and in the long-run carbon emissions are also a limiting factor for gas. Hydropower development is slowing due to environmental impacts and increasing investment costs. Biomass resources are scarce, and several other applications have higher value than power generation. Geothermal resources and development costs are uncertain, and ocean energy is in its infancy. Lastly, due to safety concerns, nuclear power is restricted to coastal areas.

An energy transition driven by renewables requires a reimagining of China's power system. 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 must be ready to reinvent itself, from market designs and regulatory setups, to product and service definitions, to stakeholder roles. Forming the 2050 power system will require substantial investments in new software alongside the new hardware described in the scenarios. Power system planning, innovation, and reform must be forward-looking. Managing uncertainty, variability, and complexity will be key.

Power system transformation and the 2035 milestone

The methodology employed involves connecting the short-term projections with the long-term imperatives, thus allowing for the establishment of more concrete milestones for the medium-term development, and thereby meet policy objectives of a Beautiful China by 2050.

A high share of non-fossil power generation is needed to enable a successful energy transition in China. In both the Stated Policies and Below 2 °C Scenarios, the power sector decarbonises, diversifies, and becomes highly flexible. *China reaches a non-fossil power generation share of 77% by 2035, and renewable generation supplies 67%.* Emissions from power generation in 2035 are reduced to 277 g/kWh in the Stated Policies Scenario and 200 g/kWh in the Below 2°C scenario. By this time wind power exceeds 1,100 GW of installed capacity and solar power just shy of 1500 GW in the Stated Policies Scenario. In the Below 2 °C Scenario, wind reaches 1,800 GW and solar 2,000 GW.

The power market reform is mature, but most likely continuously evolving

In either scenario, by 2035 the power market can fully promote efficient utilisation of the entire system, while promoting the development of low-marginal-cost renewable power. Generation quotas and inflexible long-term physical contracts are replaced with flexible spot-indexed contracting and/or market trading hedging products. Spot and balancing markets across the country are interconnected in real-time, if not completely integrated.

Flexibility services are valued, priced, and provide commercial incentives for developing flexibility. By 2035, in either scenario, flexible resources play significant roles in the system. The electricity supply and demand sides provide different kinds of flexibility services, with efficient signals from a power market. The Below 2°C scenario includes additional diverse flexibility resources, allowing more efficient integration of renewables and faster reduction of CO_2 emissions. With reductions in storage costs, the scenarios include 400-600 GW of accumulated storage capacity in the system by 2035. With increasing electrification, the demand side also increasingly provides flexibility, and smart charging of electric vehicles plays a central role in ensuring the system balance.

Natural gas based power production is expensive relative to cleaner technologies for electricity as well as power system balancing. We anticipate China's energy transition will involve a leapfrogging of gas-based power for economic as well as environmental reasons.

Interprovincial and interregional transmission capacity expands with demand increases and RE deployment. Grid expansion is firstly driven by the growth of electricity demand and then increasingly in order to balance the system and allow for integration of a high penetration of renewables. The grid becomes increasingly interconnected, dynamically operated, according to the imminent needs of the system. The broader grid footprint enables smoothening of RE resource variability, connection of RE resource regions with demand, and wide-area sharing of balancing and reserve capabilities.

This chapter details the main scenario results for the power system at a system level. The chapter starts with a description of the methodology, and then has three subsections describing the short-term outlook based on the current policy targets and market conditions, long-term outlook within the vision of a Beautiful China, and the transformation of the power system.

7.2 Power Sector scenario framing

Policy boundaries in the short-term

The scenarios in the power sector further specify the evolution of this critical sector in the short, medium, and long term, within the framing of the overall energy system scenarios. In the short-term, the scenarios are bound by stated policies affecting the power sector and trends for capacity deployments and supporting mechanisms.

Energy and environmental protection policies are considered in both scenarios; such that political effects are reflected in the results. Publicly stated policies relevant to power sector scenario model inputs are listed in Table 7-1.

Table 7-1: Stated policies which influence the power sector development

Policy name	Date	Period	Targets
Energy 13th Five-Year Plan and Renewable Energy 13th Five-Year Plan	2016	2016-2020	Renewable power generation capacity including wind, solar, biomass, geothermal, pumped-hydro and ocean energy Natural gas share short-term target
Energy Production and Consumption Revolution Strategy (2016-2030)	2016	2016-2030	Total primary energy consumption, non-fossil fuels share, carbon and energy intensity reduction, energy self-sufficiency Natural gas share mid-term target

North China Clean heating plan	2017	2017-2021	New heat supply from coal clean heating, natural gas, biomass, MSW, solar, geothermal and heat pump, etc.
Environment 13th Five-Year Plan	2016	2020	Reduction of coal consumption in key areas
Three-year Blue Sky Protection Plan and 13th Five-Year Plan for Environment Protection	2018	2018-2022	Total coal consumption, shares of coal for power generation, pollutant emissions, shares of the natural gas in the total energy consumption
Monitoring and Early Warning Mechanisms for Coal-fired / Wind / Solar Plant Planning and Construction	2016/2017	N/A	Restricted areas for new investments of coal-fired, wind, and solar plants

The 13th Five-Year Plan for renewable energy sets minimum targets for renewable energy capacity and pumped storage. Where possible, these targets are implemented in the scenarios at the provincial level. The 13th Five-Year Plan for Energy includes goals for expanding natural gas. The Energy Production and Consumption Revolution Strategy (2016-2030) provides a comprehensive set of targets on the shares of non-fossil fuel and natural gas. The North China Clean heating plan (NCCHP) set targets for clean energy heating, linked to district heating, combined heat and power and electricity for heating via heat pumps or electric boilers.

The Three-year Blue-Sky Protection Plan and 13th Five-Year Plan for Environmental Protection set limitations on coal, particularly in key economic regions. The monitoring and Early Warning Mechanisms for coal power, wind, solar planning and construction each set restrictions on adding new wind, solar, and coal-fired plants in various provinces from 2017 through 2020. Taken together, these policies create a tight bound on the energy system's development within a scenario context in the short-term until 2020.

Power Sector Scenario Strategy

In both CREO scenarios, China's power sector transforms in accordance with the overall vision of a clean, low-carbon, safe, and efficient economy and society.

Clean and low-carbon solutions

Clean and low-carbon both imply that coal use in the power sector will decline and replaced by cleaner fuels. The scenario boundary conditions limit the energy sector to 1 billion tonnes of raw coal consumption per year by 2050, which drives coal reduction in the power sector. The power sector is constrained to a maximum usage of 550 Mtce of coal by 2050 in the Stated Policies Scenario. Furthermore, we include the target from the Energy

Production and Consumption Revolution Strategy (2016-2030) policy, which states that the share of non-fossil electricity is to exceed 50% by 2030.

Not only does the power sector decarbonise, it expands while also enabling the decarbonisation of other sectors through electrification. Electricity consumption increases while most other direct forms of energy end-use decline.

Natural gas rises modestly in the short-term

Increasing the share of natural gas in power generation can reduce air pollution emissions and natural gas emits less CO_2 per unit of energy production than coal. China achieves its target of 10% share of primary energy as natural gas by 2020 in both scenarios, and gas accounts for consumption of 56 Mtce in 2020. In the Stated Policies Scenario, natural gas consumption increases to 15% by 2030, amounting to 177 Mtce in the power sector. Thereafter, given the rise in renewable energy deployment, natural gas (on average) ceases to contribute to decreasing carbon emissions. The Below 2 °C Scenario involves faster decarbonisation, and in this scenario gas-fired power hits a plateau in 2020 and declines thereafter.

Carbon pricing helps drive efficient, low-carbon development

In both scenarios, carbon pricing via the national emissions trading system strengthens after 2020, when it begins to provide a robust incentive for low-carbon power generation. In this projection, CO_2 prices in the power sector rise linearly from RMB 50/tonne in 2020 to RMB 100/tonne in 2040. In the Below 2 °C Scenario, a hard cap is set for power sector emissions to ensure that cumulative emissions through 2050 stay within the scenario boundary for the overall energy system. Shadow price analysis indicates that the cost of CO_2 emissions in the power sector would increase to RMB 150-170/tonne around the year 2030 and RMB 250-280/tonne by 2050. To put these numbers into perspective, during the fall of 2018, the EU carbon price averaged roughly RMB 150/tonne.

Flexibility enables a safe, reliable, and secure system

To balance electricity supply and demand with a high penetration of renewables, the system must develop flexible resources. Reliability will depend on greater sharing of resources between regions, through a strong grid, and advanced coordination between grids. Reliability will also depend on introducing a variety of power sources that can reduce the risk of failure due to weather related technical failures and shortage of resources and fuels. Safety also includes the government's decision not to develop inland nuclear plants, keeping nuclear development to the coast, and limiting nuclear capacity to 120 GW.

Power markets promote economic efficiency

Advanced power markets enable China to efficiently use energy and manage the increasingly complex and diverse power system with an increased reliance on variable renewable sources. Historically, China has promoted the build-out of the thermal power fleet with fixed-operating-hours contracts and generation rights, a policy which encouraged investment to meet surging electricity demand, but today reduces the efficiency of investment and dispatch. These fixed contracts are thus being progressively phased out. As renewable penetration rises, thermal plant owners must find new roles via flexibly balancing and shoring up system security, or gradually retire. The power markets shall aid in determining which resources should be deployed where, and operated when, through clear price signals motivating least-cost development of grid, generation, storage, and demand response from an overall system point of view.

Evolution of renewable policy support will continue

China's renewable feed-in tariffs currently provide different renewable energy varying levels of support. Recently, policy-makers have begun to phase out the primary wind and solar feed-in tariffs (FITs). As wind and solar technologies mature and their prices fall, they will gradually become competitive and be deployed based on market prices. Solar capacity has recently grown quickly, in part due to receiving higher subsidies than wind. As solar costs decline the required subsidy for achieving a specific level of deployment is reduced. This is reflected through a scenario boundary that increases the minimum share of solar power in the electricity mix. Once market parity is achieved, this constraint is no longer binding, as deployment then is based on least-cost principles.

Table 7-2: Boundary conditions for solar

	2018-2020	2020	2025	2030
Trend (GW/year)	30			
Support level Stated Policies		3.7%	7.7%	12.5%
Support level Below 2 °C		3.7%	8.5%	14.5%

In the near-medium term, we expect a shift in policies to favour a combination of technology-specific targets for wind and solar. This is due to the need to ensure a diverse resource mix, regionally balanced renewable development, grid planning, and least-cost investments. After 2030, we anticipate only newer technologies such as geothermal power, ocean energy, and concentrating solar power (CSP) will require policy support.

Implementing a vision of a Beautiful China for the power sector

In 2050, the power system shall enable and harmonise with the vision of a Beautiful China, which encompasses both environmental sustainability and cost efficiency. In both CREO scenarios, back casting from 2050 ensures that medium-term targets and milestones are in accordance with overall boundary conditions throughout the analysis period.

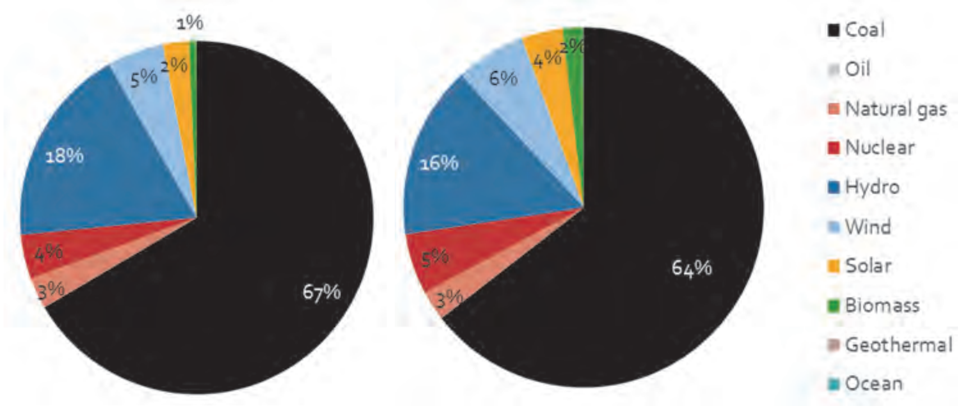
7.3 Short-term outlook for the Power Sector

The short-term power sector outlook (2017-2025) covers the completion of the 13th FYP through the 14th Five-Year Plan period. In both CREO scenarios, current government policies and targets heavily shape short-term power sector development. The Stated Policies Scenario strictly follows energy policies already adopted, while the Below 2 °C Scenario follows these policies while also assuming a fixed carbon budget, which takes effect after 2020. Gross power consumption grows from 6,300 TWh in 2017, to 7,700-7,900 TWh in 2020. By 2025, gross power demand is 9,400 TWh in the States Policies scenario and 9,900 TWh in the Below 2 °C Scenario.

Power generation mix and non-fossil share

In 2020, coal-based generation still supplies over half of power demand in China, while renewable generation contributes with a quarter of the total. Renewable installed capacity accounts for about half of the total, but solar and wind plants have relatively low capacity factors relative to coal plants. Natural gas releases little growth in generation share, whereas oil is too expensive to use for power generation and all but disappears from the power generation mix by 2020.

Figure 7-2: Power generation share in 2017 and 2020

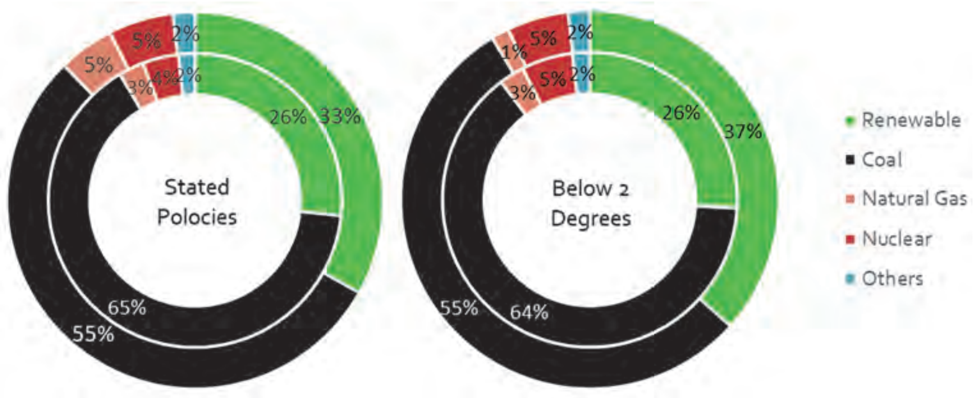


2017 2020

After 2020, the projections in the two scenarios depend less on technology-based capacity targets and rely more on China's targets for non-fossil generation, such as the 50% non-fossil electricity generation target for 2030 set in the Energy Production and Consumption Revolution Strategy (2016-2030)[130]. Both scenarios achieve this target. The Stated Policies reaches a 51% non-fossil share and the Below 2 °C Scenario projects a 63% share by 2030.

In the 13th Five-Year Plan for Electricity, the NDRC targeted for natural gas power plants to reach 110 GW by 2020, contributing to more than 5% of the total power mix. Both scenarios take the 2020 target for overall natural gas consumption target (10%) into consideration, but gas consumption in the power sector only accounts for 2.7-2.8%. The capacity of natural gas plants in 2020 is over 112 GW, exceeding the 13th Five-Year Plan indication. Natural gas supplies 5% of generation by 2025 in the Stated Policies Scenario. In the Below 2 °C Scenario, natural gas capacity declines to achieve decarbonisation targets. In both scenarios, a significant fraction of the coal fleet is retrofitted to increase operational efficiency and flexibility, and more-flexible coal capacity remains a cost-competitive power source through 2025.

Figure 7-3: Generation mix in 2020 (inner circle) and 2025 (outer circle)



New installations in the short-term challenges coal power's dominance

Through to 2025, coal power still the accounts for the largest proportion of the total generation capacity mix. However, it declines from 58% of generation capacity in 2017 to 52% in 2020, and down to 37%-39% in 2025. The installed capacity of wind and solar power generation increase rapidly in both scenarios, although the analysis complies with the restriction on investments in solar PV and wind projects in regions currently afflicted by very high curtailment rates. Notably, the 13th Five-Year Plan stipulates 5 GW of offshore wind farms to be built by 2020 – equal to 2.2% of total wind power capacity. The capacity of hydro power plants grows slightly, as does geothermal energy. Biomass power grows by a factor of three to four times by 2025, but still only contributes with just 2.3% of the total power capacity in 2025. Biomass-fired capacity growth, led by agricultural residues and waste incineration, is mainly a means to realise targets in the North China Clean Heating Plan, and it is likely that the pace of biomass deployment exhibited in the scenarios will be difficult to achieve. Ocean power technology, still in the R&D phase, grows to only 300 MW by 2025. Installed capacity for the power sector in the short-term is displayed Table 7-3.

Table 7-3: Installed capacity by technology in the short term

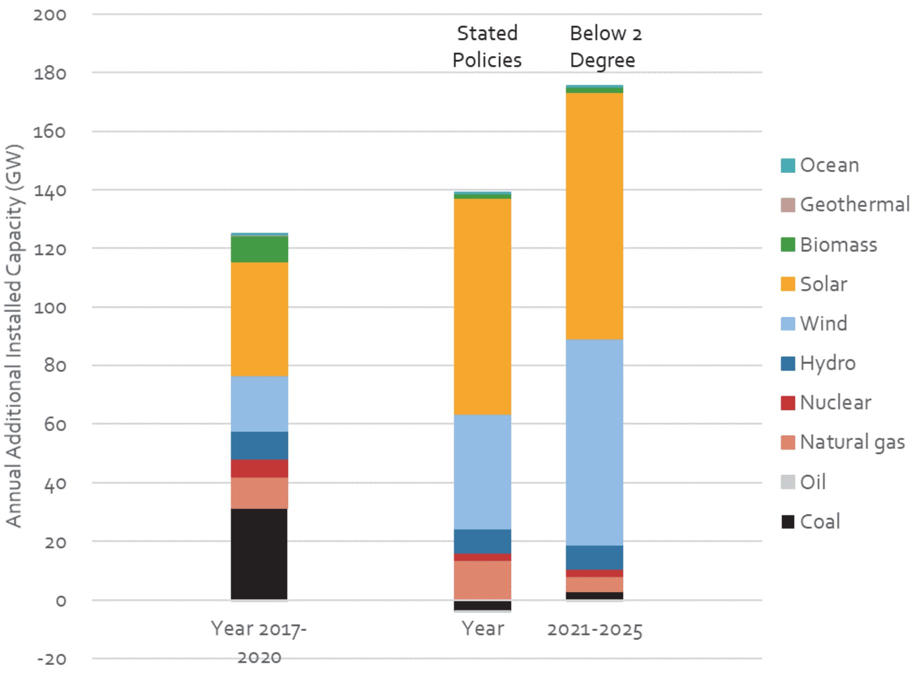
Unit: GW	2017	2020	2025	
			Stated Policies	Below 2 °C
Total	**1748**	**2124**	**2798**	**2985**
Fossil fuels	**1090**	**1217**	**1265**	**1250**
Coal	1012	1103	1083	1113
Natural gas	76	113	180	136
Oil	2	2	1	1
Nuclear	**36**	**58**	**70**	**70**
Renewables	**621**	**849**	**1463**	**1665**
Hydro	313	343	385	385
Wind	163	225	421	572

Biomass	15	48	55	57
Solar	130	232	601	650
Geothermal	0.027	0.527	0.532	0.531

As China shifts towards a clean and low carbon power system, both scenarios feature solar and wind power generation capacity growing steadily from 2017 to 2020 and more rapidly during the 14th Five Year Plan period. This is driven by non-fossil targets, improved economics, resolution of curtailment issues, resolution of some transmission constraints, and improved power market operations.

Solar capacity installations are roughly 74 GW annually during the 14th Five Year Plan period, and wind around 39 GW per year during this period. This can be compared to the annual capacity growth anticipated by targets in the 13th Five-Year Plan period of 40 GW and 20 GW, respectively. Hydropower develops according to the national strategic development plan. Other renewables such as biomass, geothermal, and ocean energy develop slowly, and appear unlikely to be a dominant technology in the near future. Through to 2025, the projections show that China's coal power capacity will continue to grow, which is due to present policy targets. Natural gas and nuclear power plant capacity will increase gradually in both scenarios through to 2025.

Figure 7-4: Annual Growth of Installed capacity during the period of 2016-2020 and 2021-2025



Power system in general in the short-term

Grid development

Both CREO scenarios employ models that map existing interprovincial transmission lines, ultra-high voltage AC and DC lines, and consider their capacity and regular operating characteristics. The model includes inter-provincial and inter-regional transmission lines outlined in the 13th Five-Year Plan as well. For years after 2020, in the absence of official plans for transmission expansion, the scenario models expand power transmission between provinces and regions to an extent that is adequate to economically fulfil the needs of power exchange, thus allowing better allocation of resources and accommodation of a high penetration of renewables in the system.

Table 7-4: Transmission capacity between regional grids in 2020 and 2025.

3		Central	East	North	Northeast	Northwest	Southern
2020	**Central**	**38**					
	East	25	**75**				
	North	8	17	**93**			
	Northeast	-	10	44	**23**		
	Northwest	24	17	35	-	**59**	
	Southern	13	1	-	-	-	**56**
2025 SP	**Central**	**41**					
	East	25	**75**				
	North	8	17	**93**			
	Northeast	-	10	44	**23**		
	Northwest	24	17	35	-	**62**	
	Southern	13	1	-	-	-	**57**
2025B2	**Central**	**40**					
	East	25	**75**				
	North	8	17	**93**			
	Northeast	-	10	44	**23**		
	Northwest	24	17	35	-	**64**	
	Southern	13	1	-	-	-	**57**

** Indication of transmission capacity a regional grid to that same regional grid indicates interprovincial transmission capacity between provinces within the same regional grids.*

The scenarios' grid expansion between 2020 and 2025 is mostly within regional grids. There is an indication of economic value in expanding transmission capacity within the Northwest, Southern and Central grid regions in the Stated Policies Scenario. In the Northwest, it's the interface between Xinjiang and Gansu province that is expanded. In conjunction with the expansion of hydropower in Tibet, the grid is reinforced towards Qinghai. In the central grid, it is between Sichuan and Chongqing where grid development needs to replace the thermal power generation locally in Chongqing with the renewable production in Sichuan.

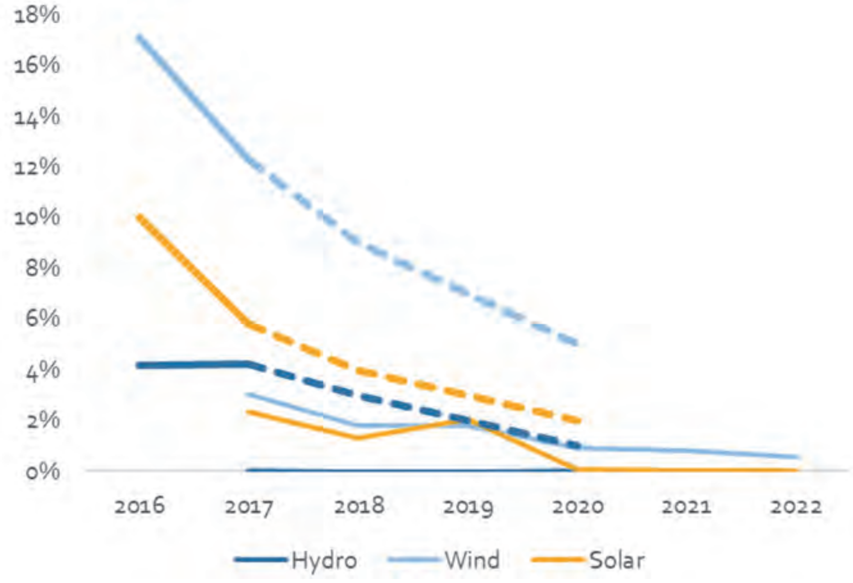
In Southern grid, there is an increase in capacity between Yunnan and Guizhou as well as a subsea connection between Hainan and Guangdong.

The Below 2 °C Scenario's grid expansions are largely along the same lines as the Stated Policies Scenario. In the Below 2 °C Scenario, the expansion between Tibet and Qinghai is larger, which supports larger wind and solar deployment in Tibet. Capacity is also added between West-Inner Mongolia and Hebei province, as both wind and solar grows more quickly in Inner Mongolia in the Below 2 °C Scenario. However, the Xinjiang-Gansu capacity expansion is absent in the Below 2 °C Scenario.

Wind and solar curtailment will improve

Variable renewables in China currently face high curtailment rates due to technical, market and operational constraints. Curtailment will continue to fall through 2025 in both scenarios. This development is contingent on firm implementation of policies that ensure wind and solar energy production is fully utilised, as well as the completion of planned transmission corridors, and resolution of provincial power trading barriers to allow greater inter-provincial transfers of electricity. It is also assumed that power market reform implementation, including electricity spot markets and more flexible inter-provincial operation, progresses rapidly. As the proportion of variable renewables increases, more flexible operations are critical to avoid wind and solar curtailment and the associated economic losses. However, the modelling suggests that some renewable curtailment is cost-effective. For instance, in the Below 2 °C Scenario, 0.45% of wind production is curtailed in 2025.

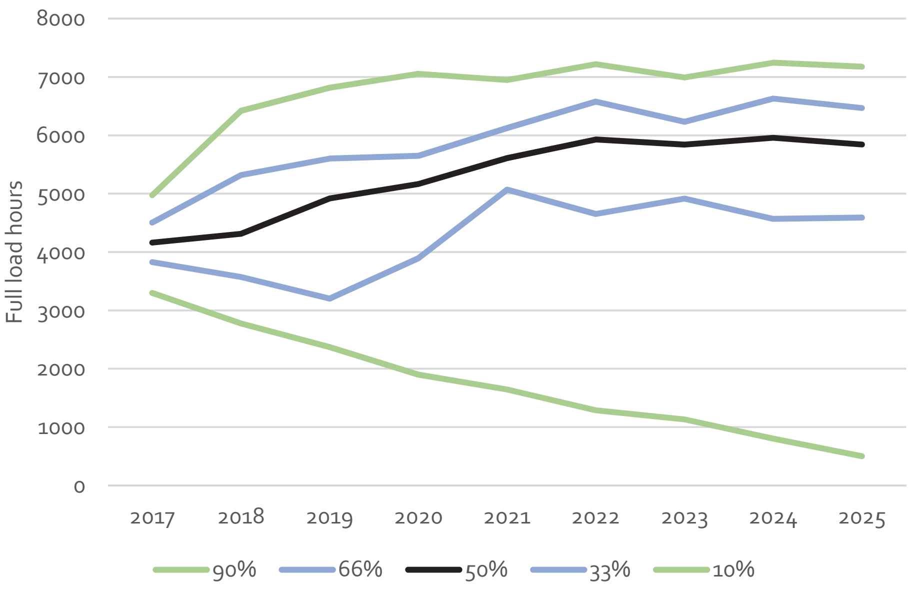
Figure 7-5: Curtailment rates of solar PV and wind power in China in Stated Policies Scenario, showing trends under current market and policy framework, versus modelling results assuming market reform



Decreasing role of generation rights

In the absence of more detailed generation rights allocation data, both scenarios employ the 2017 full load hours of thermal power generators in each province as a proxy for generation rights and implement this as a near-term requirement. It is assumed in the scenarios that market reforms progress, and minimum annual full load hour requirements decline by 20% per year and reach zero in 2025.[131]

Figure 7-6: Percentiles for coal-fired power generation FLH in Stated Policies Scenario. Percentiles are calculated across different types of coal generators in different provinces.

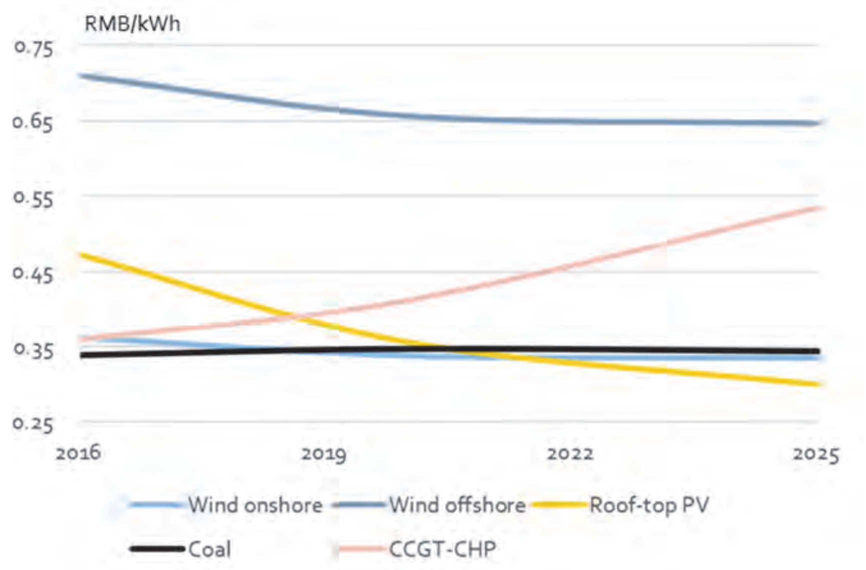


The introduction and expansion of spot markets will gradually ensure that production and consumption schedules are not locked-in by physical bilateral contracts between thermal generators and large consumers or power marketing companies. The combined effect of electricity demand growth and the restrictions on new coal plants until 2020, allows, the average full load hours for coal-fired generation to increase from around 4148 in 2017 to 4800 in 2025 in the Stated Policies Scenario. Market competition gradually pushes annual achieved full load hours of uneconomic plants down, despite the increasing average full load hours.

Competitive cost of RE technologies – achieving grid parity on the supply and demand sides

The figure below displays the assumed development in levelised cost of electricity (LCOEs) for typical electricity generation technologies. As the anticipated cost of solar and onshore wind falls, and the costs of emissions and/or fuel increases, the figure illustrates how RE technologies can achieve cost parity during the 2020-2025 period, and FiTs in their present form will therefore be phased out by the end of the short-term outlook.

Figure 7-7: Levelized cost of electricity for various power sources in short term



7.4 Beautiful China vision for 2050 – implications for power sector

The vision for a Beautiful China in 2050, and its consequences for the power sector, were detailed previously in Section 7.2. The specific implications of this vision for the power sector are detailed in the table below.

Table 7-5: Targets, restrictions and resulting boundary conditions for the power sector in 2050

Element	Ambition/target	Implication
Electricity demand	45% of final energy demand from electricity.	Power sector has a fixed demand to deliver.
Coal usage	Total annual coal usage for the entire energy sector under 1 billion tonnes. Power sector may utilise remainder after coal demand from industry and buildings is met.	Power sector has a maximum amount of coal available for use.
Natural gas usage	Natural gas shall comprise 15% of total final energy demand. Power sector shall utilise remainder after demand from industry, transport and buildings is met.	Power sector must utilise a minimum amount of gas.
Nuclear	Nuclear capacity will be increased, through restricted to the coastal areas, resulting in a total capacity of 120 GW	Capacity location is fixed. Sector is free to utilise this capacity.
Hydro	Hydro power is fully developed, reaching 532 GW. Results in an assumed production of 1,831 TWh in 2050.	Capacity, location and generation are all fixed.
Other RE	Resource restrictions for each technology type are developed on a provincial level based on resource assessments.	Maximum capacity in each province for each RE technology.

CO_2 emissions (Below 2 °C only)	Cumulative emissions between 2017-2050 must by less than 230 Gtons	Power and DH limited to 90 Gt between 2020-2050, reaching 919 Mtons/year in 2050

Power system in 2050

For 2050, the Stated Policies Scenario considers the parameters outlined in Table 7-5 in determining the following production and consumption elements of the power and heating sector energy:

- Electricity and district heating demand
- Maximum coal usage
- Minimum natural gas usage
- Nuclear capacity
- Hydro capacity and annual production

Adhering to these requirements and restrictions, the power and heating sector can is developed according to least-cost principles. This results in a power system, including generation and capacity mix, to supply electricity and heat demand.

Figure 7-8: China installed power generation capacity mix in 2017 and 2050

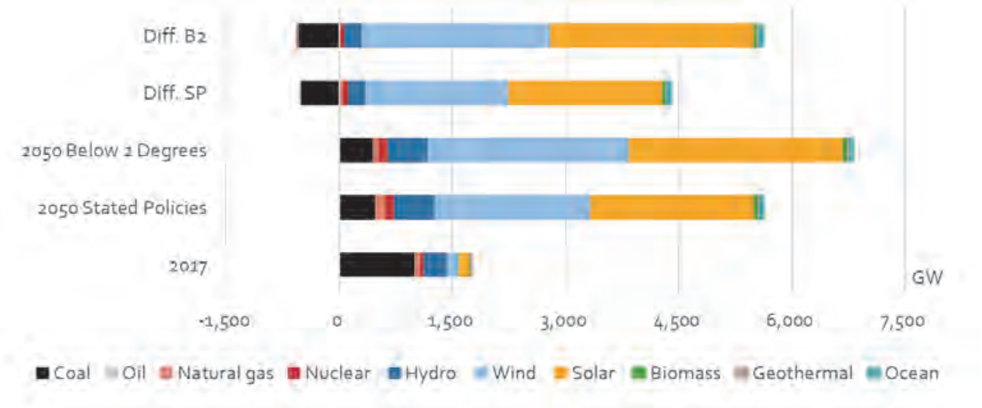


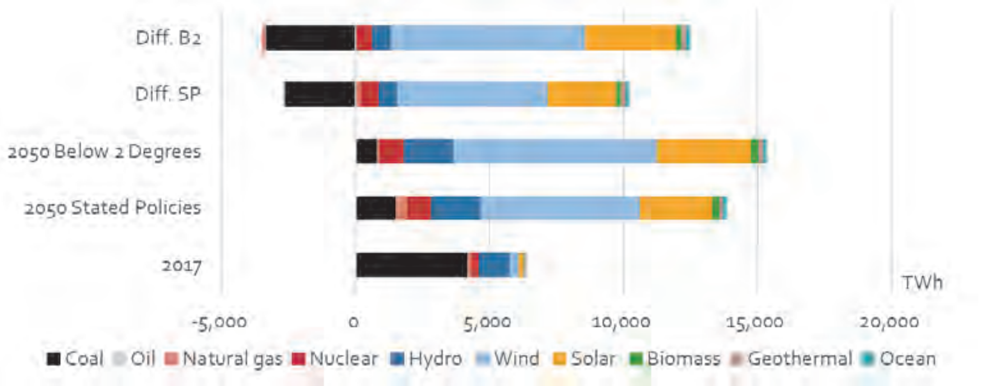
Table 7-6: China installed capacity by technology in the long term

Unit: GW	2017	2050	
		Stated Policies	Below 2 °C
Total	**1,748**	**5,626**	**6,814**
Fossil fuels	**1,090**	**622**	**536**
Coal	1,012	492	460
Natural gas	76	130	76
Oil	2	-	-
Renewables	621	4,884	6,159

Hydro	313	532	532
Wind	163	2,062	2,664
Biomass	15	55	57
Solar	130	2,165	2,836
Geothermal	0	20	20
Others	0	50	50
Nuclear	**36**	**120**	**120**

To comply with its long-term development plan of transitioning to a green and low-carbon energy system, China strictly constrains coal usage in the power sector in both scenarios, and it will adopt renewables and other types of clean energy instead. As is shown in Figure 7-8, coal capacity declines drastically between 2017 and 2050 in both scenarios, whereas coal-fired electricity generation is reduced even further (Figure 7-9), as full load hours decline to 3100 in the Stated Policies Scenario and 1800 in the Below 2 °C Scenario. This suggests a change in the role coal plays in the power sector, shifting from baseload to load balancing and enhancing the flexibility of the power system. Meanwhile, wind and solar capacity and generation see substantial growth. A robust grid and mature energy storage system allow for more efficient renewable energy integration, which is also aided by continued growth in hydro capacity and output. Capacity and generation from natural gas power rises modestly, while newly built capacity of nuclear is limited, capacity and consequently generation is expanded.

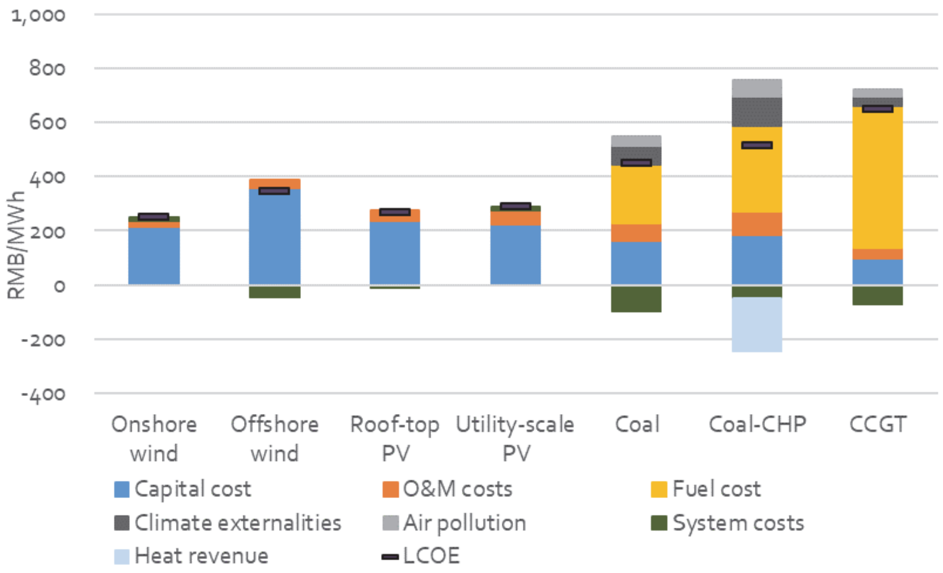
Figure 7-9: Power generation mix in 2017 and 2050



Economics in power generation points to renewable electricity in 2050

In the modelling of both scenarios, costs are a critical factor determining the composition of the power sector in 2050. Both projections depend on an in-depth analysis of the levelised cost of electricity for relevant technologies. The results of this analysis, including the anticipated system integration costs given a range of resource conditions, are displayed in Figure 10.

Figure 7-10: Comparison of levelised costs of electricity (LCOE) by technology in 2050

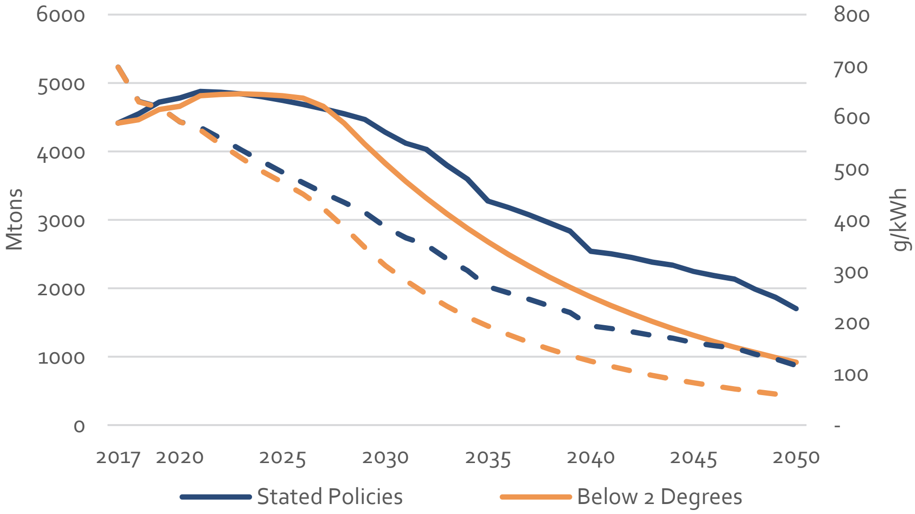


The most competitive scalable technologies are included in the LCOE chart. It indicates, a significant cost-competitive advantage on an LCOE basis of wind and solar PV, which to coal and natural gas. Air pollution and climate externalities (CO_2 price) are included for the fossil fired generation. The average system profile costs in the scenarios, are also indicated, which is defined by difference in relative system value (or fair market electricity prices) of the specific technology, to the portfolio average. The negative system cost of coal and gas-fired generation is indicative of the value of balancing the load and VRE generation. The negative system cost of roof-top PV and offshore wind shows a system benefit of localisation near demand. Taking these elements into account, the difference in LCOE strongly indicate that wind and solar are the cost-efficient generation technologies in the long-term, meaning that clean and low-carbon is also efficient from an economic perspective.

The Below 2 °C Scenario requires further action in the power sector

The implementation of the Stated Policies Scenario represents a clear break from the historical trends in the direction of low-carbon and clean electricity and energy provision. However, the Stated Policies Scenario is insufficient to achieve the goals of the Paris climate agreement. To achieve this, in the Below 2 °C Scenario the power sector must further reduce emissions, while still satisfying China's total power demand. This entails additional low-carbon generation. As is highlighted in Figure 7-11, the reduction of CO_2 emission takes place earlier in the Below 2 °C Scenario than in the Stated Policies Scenario. The additional power sector CO_2 reductions in the Below 2 °C Scenario amount to 780 million tonnes per year in 2050, and power generation CO_2 intensity decreases from 115 g/kWh to 60 g/kWh.

Figure 7-11: CO₂ emission (bold line) and CO₂ intensity (dashed line) in each scenario



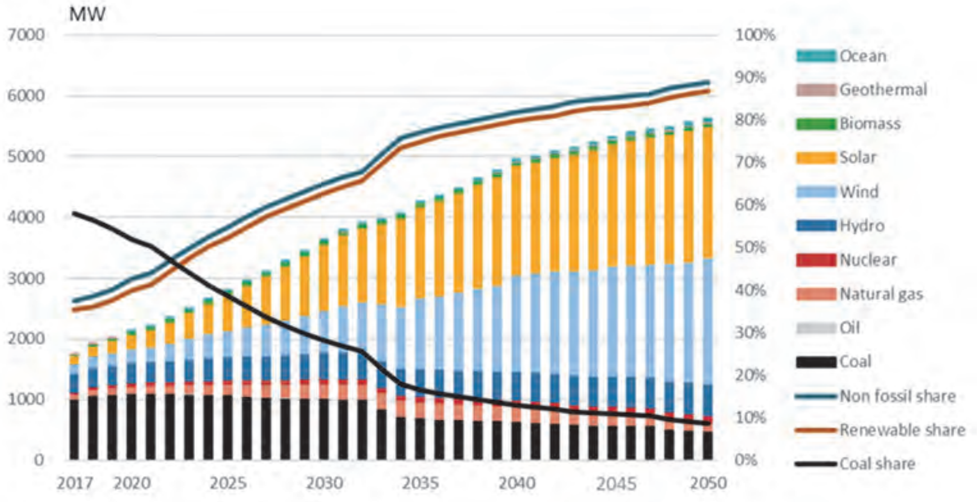
7.5 Power System transformation in the Stated Policies Scenario

The following section describes the development of the power system towards 2050 and provides insight into the key underlying aspects of this evolution.

Electricity capacity and generation

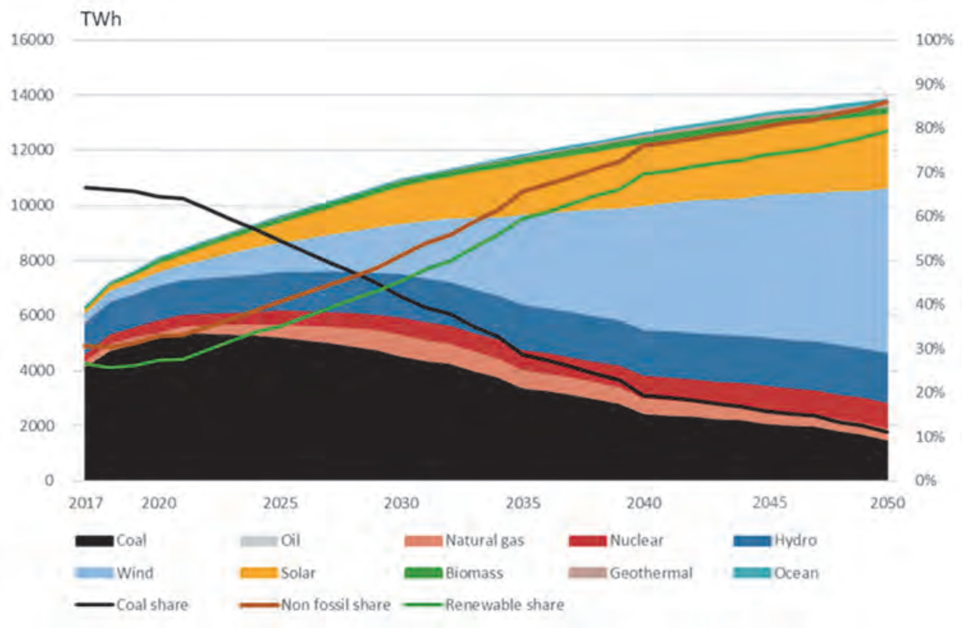
The evolution in installed capacity is displayed in Figure 7-12.

Figure 7-12: Installed capacity by technology through to 2050 in Stated Policies Scenario



The corresponding development in electricity generation through to 2050 is displayed in Figure 7-13. The share of non-fossil fuel triples from 2015 to 2050, reaching 86% in the Stated Polices scenario, whereas the share of coal generation decreases to 11%. Non-fossil sources become the backbone of the power sector.

Figure 7-13: Generation by technology through to 2050 in Stated Policies Scenario



The above figures illustrate several developments for the Chinese power system through to 2050. These are summarised in the table below, and more in-depth analysis of the key aspects is provided later in the chapter.

Table 7-7: Overview of reflections on the power sector through to 2050

1) A new role evolves for coal The current and historic backbone of the power system undergoes a shift from provider of baseload, to provider of flexibility and inertia. Greater flexibility results in: - Higher realised power prices - Less curtailment - Lower system costs - Lower coal usage and CO_2 emissions
2) Solar and wind drive supply side growth A growing demand for RE combined with increasingly lower solar and wind costs results in the majority of new capacity being VRE.
3) Role of natural gas expands significantly Natural gas is important for a diversified energy system as well as lowering the usage of coal in regions with high air pollution. The exogenously determined minimum usage in the power and heat sector results in significant growth in costly natural gas-based power and heat production.

4) Relatively limited use of biomass for power and heat production
Biomass resources in China are relatively limited, and therefore a significant proportion of these resources are utilised in non-power and heat energy sectors.

5) Hydro development corresponds to the national plan and the potential is not as attractive as before.
Hydro resources are limited while developing costs are increasing. Considering the social benefits and high energy system value, large hydro plants are planned. However, hydro plants should be used in a more flexible manner.

6) Nuclear power develops in coastal regions, and plays a minor role
Due to environmental and safety concerns, and following national plans, nuclear power plays a minor role, by assumption and scenario design.

7) Oil use fades out from the power sector
Due to its high fuel cost and high CO_2 emissions, oil will be phased out from the power sector and replaced by other generation.

Power market reform and its development

To achieve the vision of a Beautiful China, power market reform is an important driver. It will strongly affect the principles of power system operation and thus the LCOEs and relative value of competing technologies. Market reform and sufficient competition between market players will lead to minimal cost and value-based investment decisions. In addition, driven by the integration of provincial and regional markets, power transmission and balancing can be achieved on a larger scale. This subsection will elaborate on the assumptions made regarding future power market development in China.

Power sector reform action plan and its status

Name	Policy reference	Date	Brief context
Notice on Further Promoting Power Generation Trading Rights	NEA Monitoring & Management [2018] No.36	2018.04.27	The notice encourages inter-regional and inter-provincial power generation trading rights.
Guiding Opinion on Improving Flexibility of Power system	NDRC Energy [2018] No.364	2018.02.28	The document promotes coal power flexibility retrofits, dispatch dedicated power sources and new energy storage technologies.
Notice to Construct Spot Power Market Pilots	NDRC Energy [2017] No.1453	2017.08.28	The document outlines the locations of 8 spot power market pilots.
Notice on the Work Plan to Improve the Compensation	NDRC Operation [2017] No.294	2017.03.29	The document clarifies the timeline on the compensation (market) mechanism for power system auxiliary services.

(Market) Mechanism of Power System Ancillary Services			
Notice of Opening Power Generation and Consumption Plan Orderly	NDRC Operation [2017] No.294	2017.03.29	The Notice provides details on suggested actions that should ensure the implementation of the power market reform document（中发〔2015〕9 号).
Notice on Constructing Trading Pilot on Distributed Power Generation	NDRC Energy [2017] No.1901	2017.10.31	The document provides direction on constructing a trading pilot with distributed power generation.
Notice to Release the Power Market Reform Supportive Documents	NDRC Economy [2015] No. 2752.	2015.11.26	Document includes six aspects: electricity price reform, power markets construction, construction and operation of electricity transaction organization, opening generation and retail markets, retail reform, and supervision and management of captive coal plants

China's present bulk power system lacks efficient and optimal power dispatch. The table above lists current power market reform policies. Both CREO scenarios anticipate that power market reforms will result in a comprehensive market structure that can better accommodate variable output from renewable energy technologies, thereby optimising the cost of fuel and ancillary services through competition. Such market optimisation is a critical piece of China's energy transition. In the projections, a fully integrated and optimised national power market is in place before 2035.

Power market reform in the scenarios

The ongoing process of power sector reform is assumed to have been successfully implemented in the scenarios. Competition is achieved during the reforming process by removing constraints included in the initial years of the scenarios. Market prices are calculated for each hour as the equilibrium between supply offers and demand bids, and the price is set in equilibrium.

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.
- Interprovincial transmission scheduling, in which flow schedules are adopted initially by setting constant levels of flow for day-time and night-time.

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.

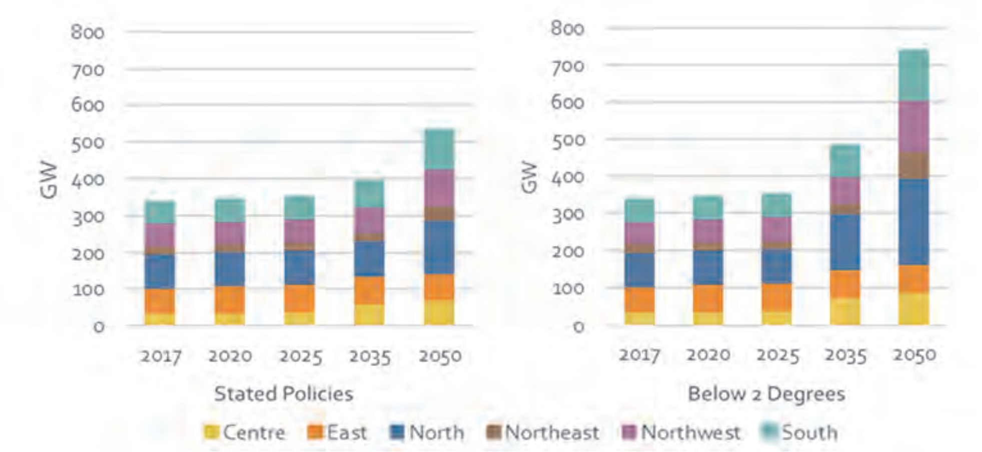
Grid development and operation

Grid planning and development

Interprovincial grid expansion is critical to provide stability and balancing support. New transmission development 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.

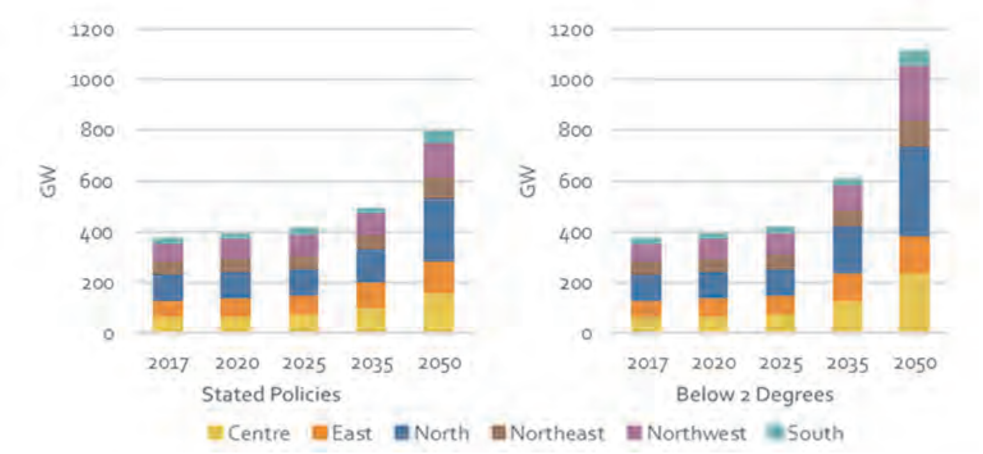
Each provincial grid is part of one six larger grid regions. Interprovincial connections can thus constitute transmission capacity between two provincial grids in the same region or each of the six grid regions.

Figure 7-14: Interprovincial grid capacity between provincial grids within the same regional grid capacity



In the Stated Policies Scenario, interprovincial grid capacity with the regional grids, is expanded by 44 GW from 2025-2035 amounting to a 12% increase. From 2035 to 2050 the grid capacity within the grid regions expands a further 140 GW or 36%. In the Below 2 °C Scenario, these expansions are three times that of the Stated Policies Scenario between 2025-2035 and 1.8 times as much capacity is added between 2035-2050.

Figure 7-15: Interprovincial grid capacity connecting different regional grids



Note that transmission capacity is counted twice in these figures, as the same link will show up in each end of the line.

In terms of interregional transmission capacity, the development is of similar scale as within the regions. In the Stated Policies Scenario, 40 GW of interregional transmission capacity is added to the system between 2025-2035, and an additional 150 GW from 2035-2050 (without double counting). In the Below 2 °C, the total interregional expansion is 95 GW between 2025-2050 and 253 GW between 2035-2050.

In summary, the total interprovincial transmission capacity in 2050 is 1.8 times todays' in the Stated Polices scenario and 2.5 times today's level in the Below 2 °C.

Figure 7-16: Power transmission between regions in 2020

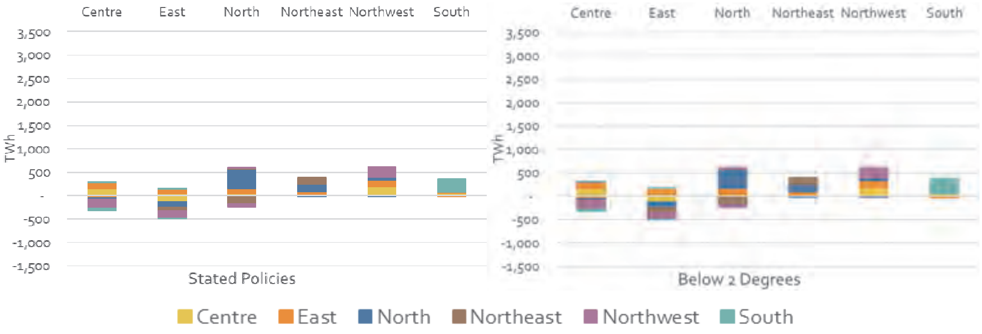
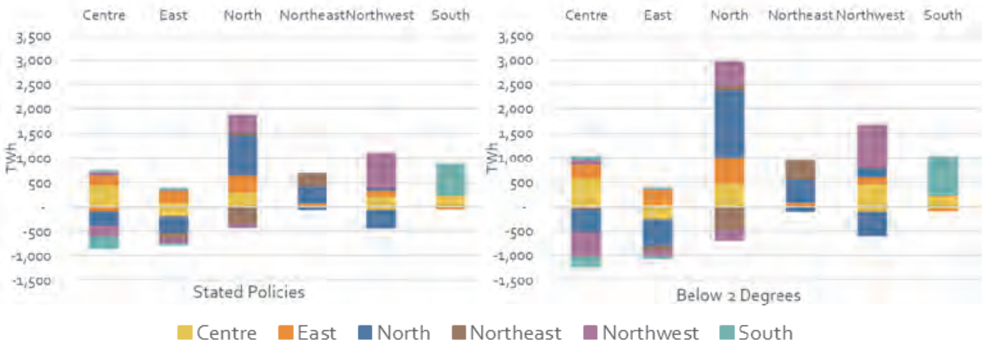


Figure 7-17: Power transmission between regions in 2035

Figure 7-18: Power transmission between regions in 2050



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.

More complex grid operation and shifted balancing paradigm

Power system operation will become increasingly complex. 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.

As variable renewable energy gradually displaces large fractions of traditional dispatchable power, this will also necessitate a shift in how demand and supply are balanced. As the marginal cost of RE generation is low, both conventional power generations as well as power demand provides flexibilities to integrate more renewable power in the system, the overall power consumption curve is therefore no longer only shaped by the need of power but also by when renewables produces power with extreme low marginal cost.

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 7-19: China power generation and consumption profile for one week, Summer 2017

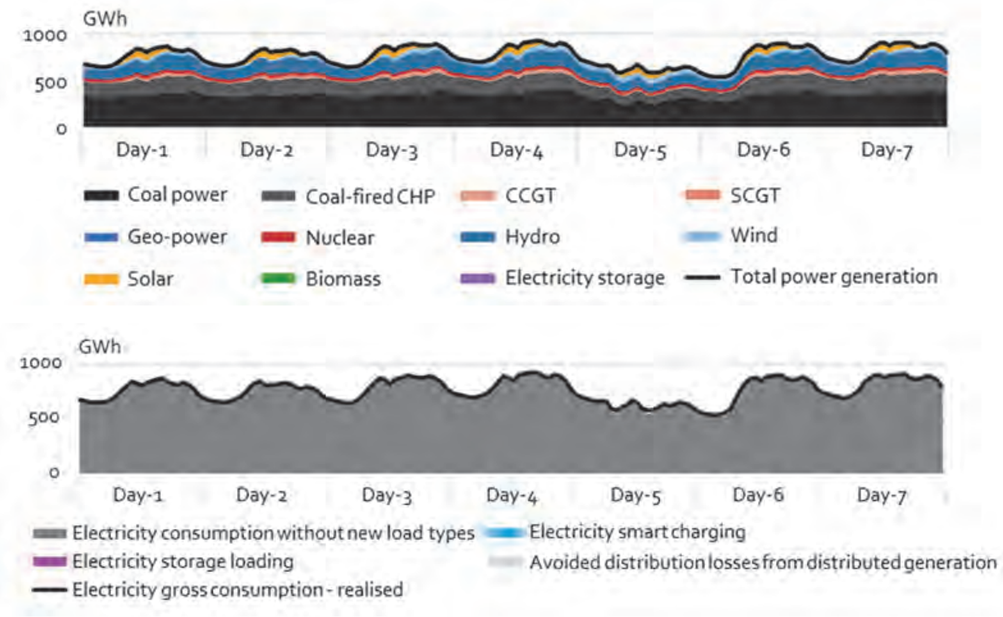


Figure 7-20: Power generation and consumption profile in China in 2020 Summer

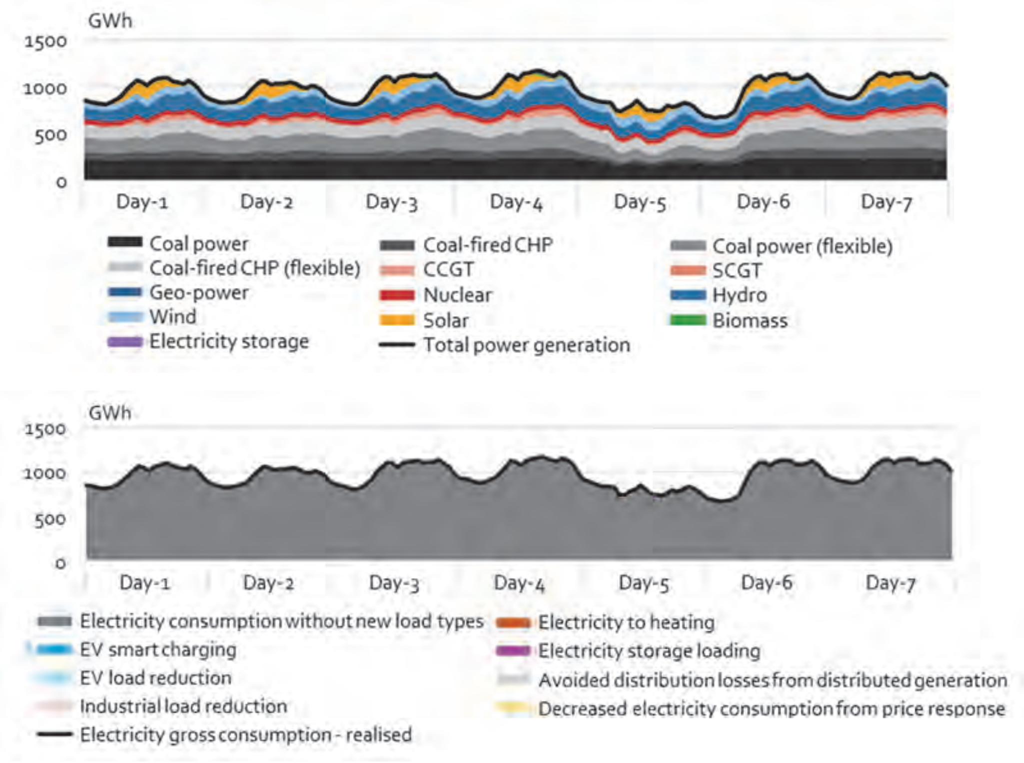
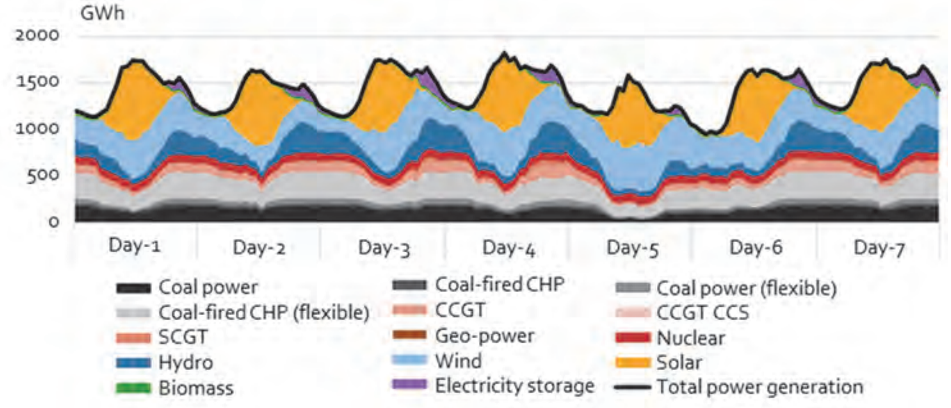


Figure 7-21: Power generation and consumption profile in China in 2035 Summer (Stated Policies Scenario)



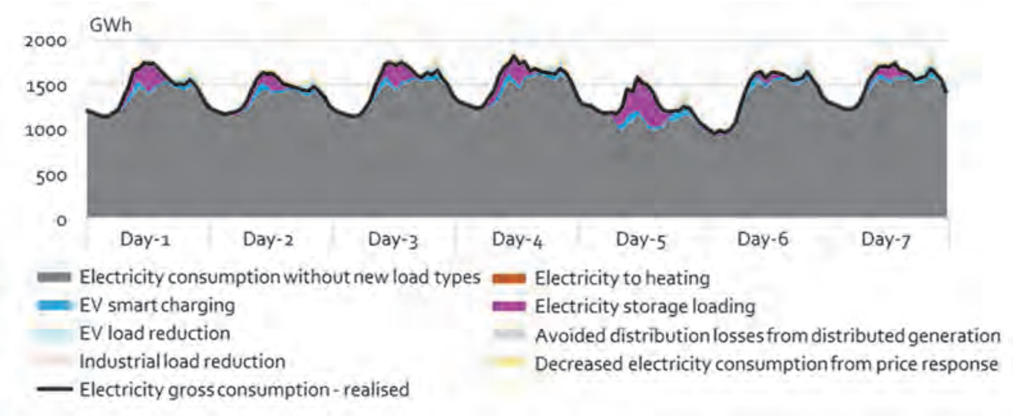


Figure 7-22: Power generation and consumption profile in China in 2050 Summer (Stated Policies Scenario)

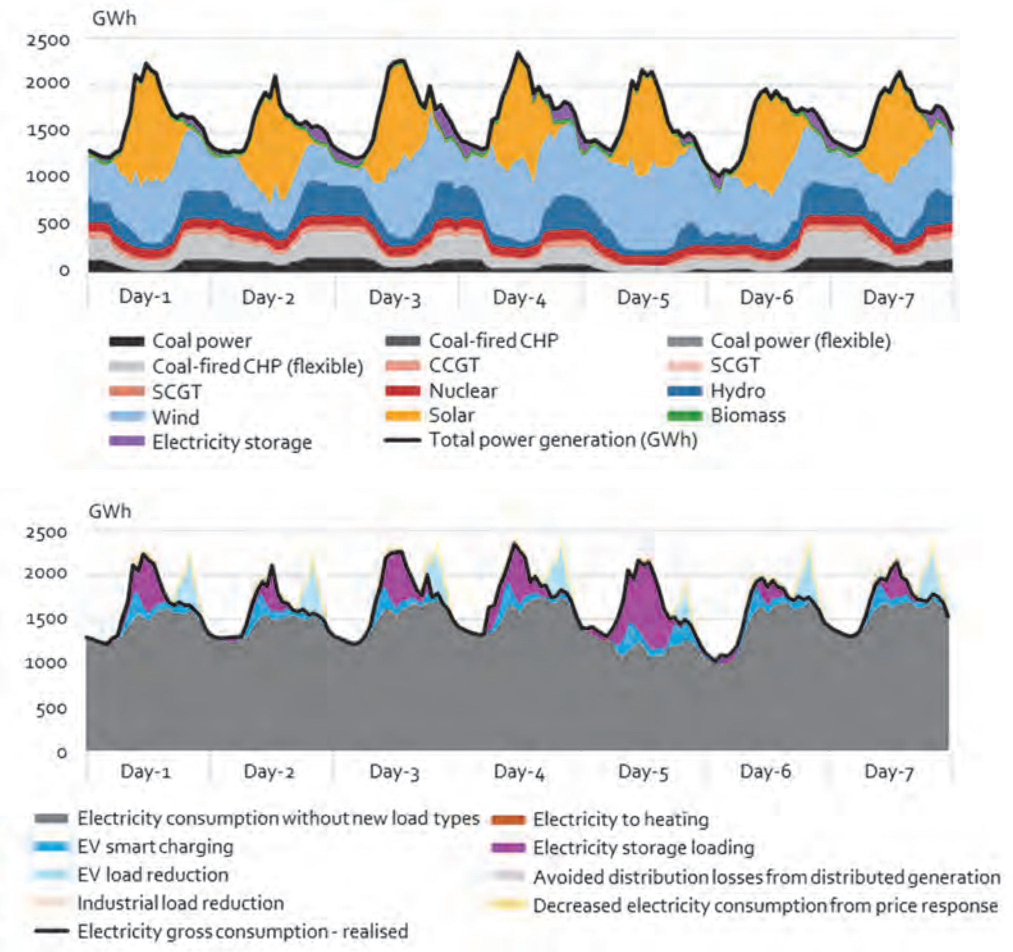
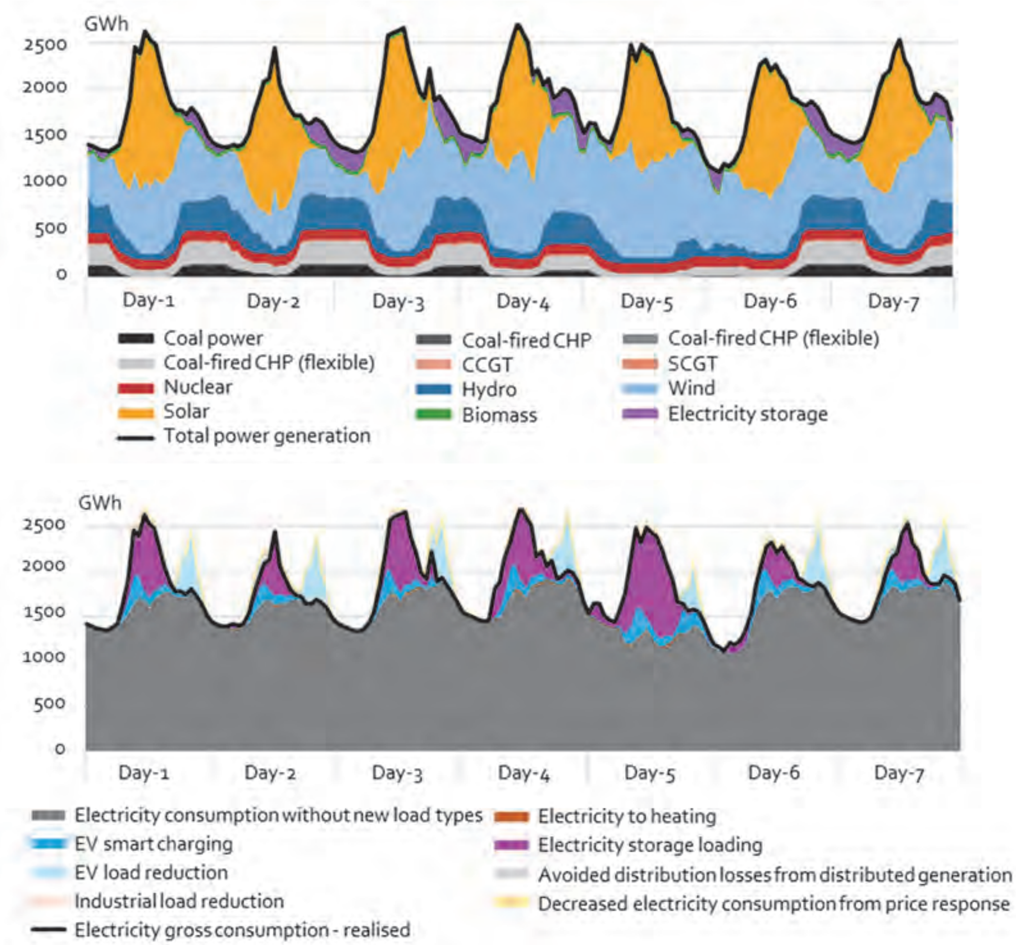


Figure 7-23: Power generation and consumption profile in China in 2050 Summer (Below 2 °C Scenario)

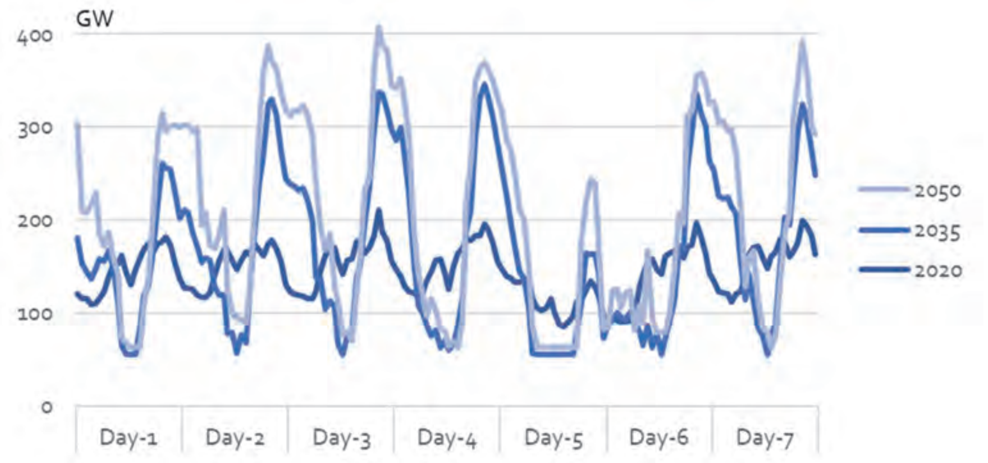


Flexibility has higher value than electricity, thus hydropower should be used more flexibly

The future energy system is supplied primarily by renewables, which significantly reduces fuel costs as well as some O&M costs. In addition, the low marginal production cost of renewables drives down electricity prices when there is sufficient renewable production. However, to maintain power system balance and to address the challenges of variability and uncertainty of renewable production, flexibility resources becomes critical to system security, and therefore have a higher value than the energy value of the kWh of output they contribute.

Hydro power plants with reservoirs have unique advantages, both in terms of providing clean energy with a low marginal cost, as well as providing controllable and flexible generation. The operational and market paradigms for hydropower in China must change, shifting from low-value baseload energy supply, to high-value system balancing.

Figure 7-24: Hydro power generation curves in State Policies Scenario, summer



Interprovincial transmission operation supports system balancing via bidirectional exchange

Figure 7-25 and Figure 7-26 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 Jiangsu. 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.

Figure 7-25: Power exchange between Shanxi province and it's connected provinces in 2020

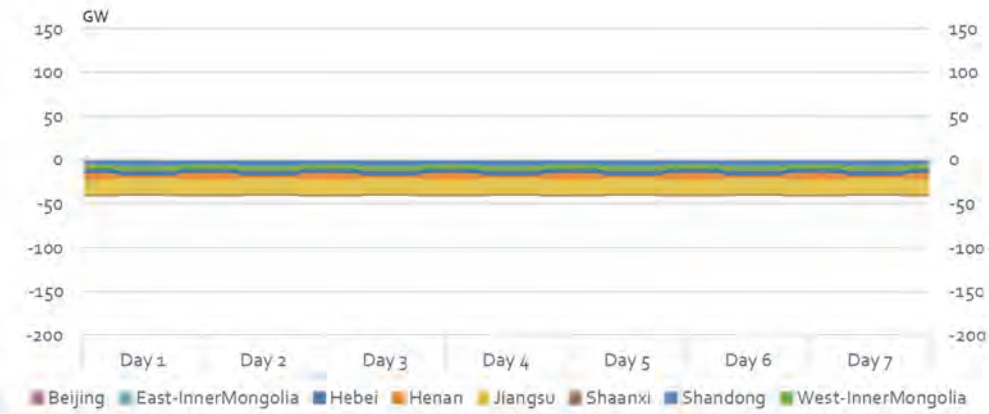
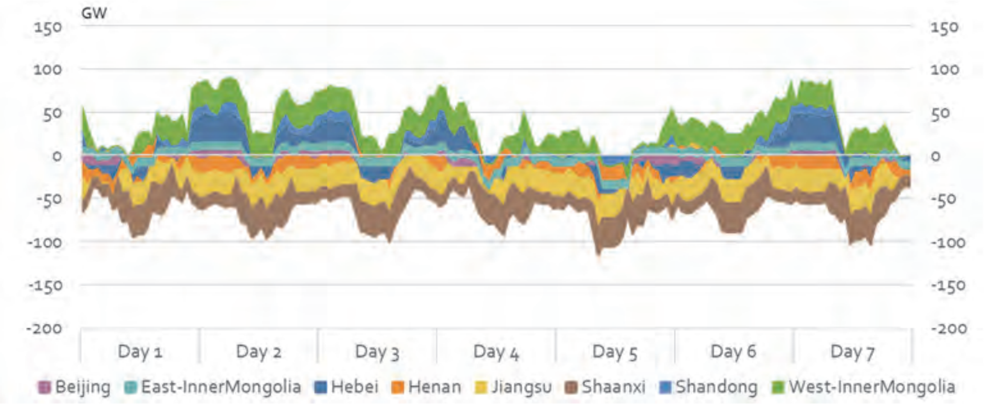


Figure 7-26: Power exchange between Shanxi province and it's connected provinces in 2035 in Below 2 Degree Scenario



Flexibility development and deployment

In addition to the flexible operation of power sources on the supply side, storage and demand response are two important manners to provide flexibility to the system.

Storage

Different energy storage technologies have various geographic availability, energy densities, capacity, and cost, and each has preferred applications. The projections in the two scenarios primarily consider seasonal and daily operation of energy storage. As the cost of storage technologies declines and market reforms proceed, energy storage plays a larger role in mid and long-term power system operation. In daily operation, energy storage predominantly charges during the daytime when solar production surpasses local electricity consumption, and discharges in the afternoon and evening when solar production reduces while consumption increases. In 2020, the capacity of various storages amounts to 1,232 MW, and will increase dramatically to almost 468 GW in 2050 in the Stated Policies Scenario.

Demand response

In both scenarios, demand response provides an important flexibility option. Demand response requires efficient market signals to reduce consumption when the supply-demand balance is tight and to motivate increased consumption when supply is abundant relative to demand. Utilising demand response as a flexibility option requires both physical flexibility from responsive loads, and the appropriate market institutions to incentivise the desired response. Therefore, while demand response is currently limited, its contribution is projected to increase in tandem with the development of market functions. In line with the increased electrification in the Below 2 °C Scenario, the capacity of available demand response is higher in this scenario. In 2020, total industrial demand response capacity amounts to 3.1 GW and in 2050 it is 15.4 GW.

Electric vehicles and smart charging

Both scenarios assume increased deployment of electric vehicles, which creates additional load as well as providing the necessity to ensure that this new vehicle fleet charges when optimal for both individual transportation needs and improving power sector efficiency and RE integration. In the absence of such optimisation – known as orderly or smart charging – EV charging would create new serious challenges for the power system. Both scenarios assume EV charging is optimised for grid balancing. The phase-in of smart charging is also a component of the power sector reform development.

Coordination between electrical grid and heat system operation

Both scenarios consider the flexibility enabled by coordination between the electricity and heating systems. CHP plants and heat pumps are the interfaces between the power and district heating systems. As power and heat decoupling is applied in CHPs, and heat pumps provide a larger share of heating in Central and East China, the coordination of heat and power generation allows the transfer of flexibility resource from one system to another. Such flexibility mainly serves seasonal and even yearly variations to enhance the security of both systems.

8 Renewable outlook

8.1 Overview and key points

As China's energy system continues its accelerating transition away from coal and towards renewable energy, particularly in the power sector, it is critical to understand the outlook for individual renewable and clean energy technologies, based on factors such as resource potential, policy priorities, and trends in costs and technology. This applies to both the main renewable technologies that will form the core of China's clean energy transition – wind, solar PV, and conventional hydro – as well as smaller but important technologies, particularly energy storage for transport and grid applications, as well as solar thermal, biomass, and ocean energy. This chapter covers the outlook for hydro, solar, wind, and biomass. The key findings regarding renewable technologies are:

Hydropower: According to the Stated Policies scenario, China's hydropower capacity, already largest in the world, will rise 70% by 2050, led by new additions in Southwest China. Hydro will essentially reach the limits of the country's technical potential. Although China's hydro plants will experience worsening economics due to greater environmental restrictions, power market reforms will also resolve curtailment issues and lead to greater utilization and optimisation of hydro resources, helping hydro complement China's clean energy system.

Wind: Under both CREO forecasts, wind becomes the leading generation source at the core of the China's power sector. Major trends affecting the sector include power reforms that help resolve wind curtailment and improve its economics relative to coal, shifts in wind development towards low-speed wind regions, and larger turbines. The costs of onshore wind and offshore wind technologies both reduces and can compete with establishing a new coal power plant. The two scenarios differ mainly by the wind resource and by the difficulty level of construction and maintenance: Wind generation rises from 328 TWh in 2016 to 1,801 TWh in 2030 under Stated Policies Scenario, whereas it rises to 3,336 TWh under the Below 2 °C scenario. In the Stated Policies scenario, wind produces 5,955 TWh in 2050, compared to the higher 7,612 TWh projected by the Below 2 °C scenario.

Solar: In both CREO scenarios, solar also shows dramatic growth, both for electricity production as well as solar thermal direct-energy applications such as heating. China already has the world's leading photovoltaic manufacturing and power industries, and ongoing cost declines will allow the sector to reach grid parity in the coming years. Under the Stated Policies scenario, we project China's solar capacity to rise 1,364 GW by 2035 and 2,034 GW to by 2050, to produce 1,858 TWh of electricity in 2035 and 2,694 TWh by 2050. The Below 2 °C scenario foresees even faster growth to 2,000 GW by 2035 and 2,836 GW by 2050. Solar thermal heating grows by a factor of four by 2050 under the Stated Policies scenario, and by a factor of 7 in the Below 2 °C scenario.

Biomass: Under both CREO projections, biomass for power generation and fuel production grows, albeit sharply limited by feedstock resources and economic considerations. As a result, biomass remains the smallest of the three renewable energy sources detailed in this chapter. Biomass power capacity rises in the projection from 15 GW in 2017 to 54 GW in 2050 under the Stated Policies scenario, and to a slightly higher 57 GW in the Below 2 °C scenario. Under the Stated Policies scenario, by 2050 biomass power produces 255 TWh of electricity, mainly from waste-to-energy and straw-fired CHP. Bioethanol production sees fast near-term growth followed by declines due to transport electrification, whereas biodiesel production sees strong growth. Direct end-uses of biomass for heating decline as the sector shifts towards electrification and CHP.

8.2 Hydropower outlook

Hydropower will remain a leading power source for China, given its attractive economics, low carbon characteristics, flexibility, and mature technology. Considering the social benefits (transportation, flood prevention, environment protection, local economics, etc.), China will continue its hydropower development in areas with abundant hydro energy resources. Though the sector faces challenges including costs and environmental restrictions, both CREO scenarios forecast energy from hydro will continue to grow through 2050, reaching the limits of China's technical hydro resources. In our projections, hydro transforms from serving as a baseload supply to forming a critical balancing resource for renewable energy nationwide, allowing hydro to benefit from favourable economics for balancing services.

Hydro growth will concentrate in Southwest China

China's hydropower resources are unevenly distributed, with the western region having a relative abundance of hydropower resources and compared to central and eastern regions. The southwest region of Sichuan, Chongqing, Yunnan, Guizhou, and Tibet has the most hydropower resources, the technical exploitation amount of which accounts for 66.7% of the country's total.

Table 8-1: China's hydropower resources[132]

Theoretical reserves	Installed capacity (100 GW)	6.94
	Generating capacity (100 GWh)	60,829
Technical exploitation amount	Installed capacity (100 GW)	5.42
	Generating capacity (100 GWh)	24,740
Economic exploitation amount	Installed capacity (100 GW)	4.02
	Generating capacity (100 GWh)	17,534

At the end of 2017 China has 312.5 GW of hydropower installed; in 2017, China added 7.12 GW of hydro capacity, an increase of 2.3%, the lowest growth since 2000. From 2021 to 2030, we project China will install 94 GW of new hydro capacity; and by 2050, total capacity is expected to reach 532 GW. In 2017, the country's conventional hydropower produced

1,153 TWh, accounting for about 18% of the country's total electricity generation. Sichuan and Yunnan accounted for nearly 50% of this figure.

Since 2014, hydro production has declined due to a large number of power plants being put into operation while new transmission corridors faced delays. Barriers to inter-provincial power dispatch coordination have also hindered full utilization of hydro. As a result, in 2017 China's annual hydro curtailment reached 51.5 TWh, of which Sichuan and Yunnan accounted for 83%. in the short-term, we anticipate policy will result in full utilization of inexpensive hydropower, resolving the curtailment issue.

According to the distribution of hydro resources and technical and economic feasibility of hydropower development and to address the current development conditions, three types of development regions are defined. The Well Developed Zone, covers the regions that have over 80% of hydropower resources developed, and little potential remains. The Optimized Development Zone covers the regions that have little and distributed potential, which will possibly not gain much capacity in the future. The Key Development Zone refers to the regions with less than 50% of its hydropower resources developed, and their unexploited resources concentrated in the main streams of major rivers mainly in Sichuan, Yunnan, Tibet, and Qinghai. The Key Development Zone is the main focus of China's future hydropower development. This zone accounts for a forecast 44% of China's total hydro capacity in 2020, 52% in 2030, and 60% in 2050. Sichuan is expected to have a hydropower capacity of over 120 GW in 2050, whereas Tibet and Yunnan are both expected to have hydropower capacity of around 100 GW. The combined hydro production of Sichuan, Yunnan, and Tibet is forecast to generate 49% of China's total hydro production in 2020, 56% in 2030, and 62% in 2050.

Figure 8-1：Distribution of hydropower capacity in 2017,2020,2030 and 2050

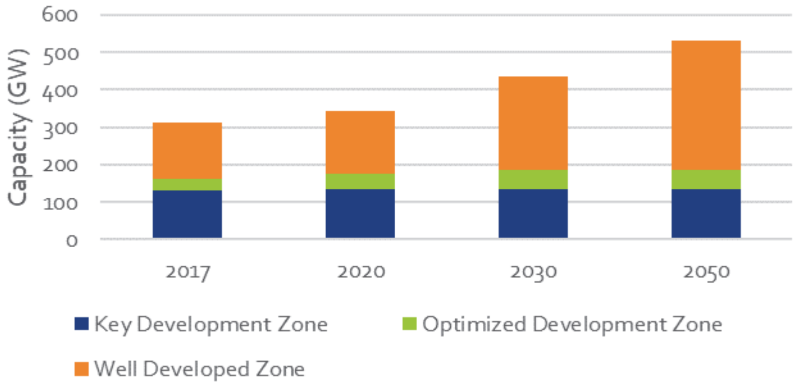
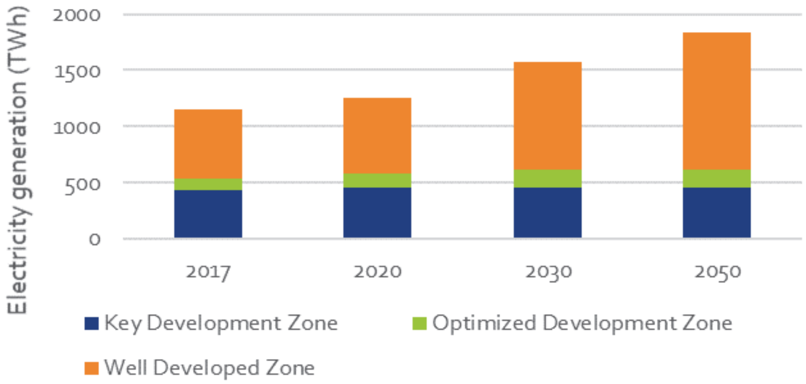


Figure 8-2: Forecast hydro electricity generation by region



Large-scale hydropower has many impacts on local economies

Hydropower development affects local economies in many ways, given the scale and long construction period of dams, upgrades they bring to local land and water transportation, migrant relocation, and boosts to local employment and taxation. Large hydropower projects also benefit downstream areas by controlling downstream floods and meeting power generation needs, but also play a prominent role in driving local economic and social development.

Hydropower development faces both challenges and opportunities

Hydropower development and operations also have great **environmental consequences** on reservoir and dam areas, downstream waters, and coastal regions. Some small hydropower stations have seriously damaged local ecology. Many small hydropower stations have been constructed without regard for relevant regulations and without proper documents. Given increased public attention to environmental impacts of hydropower plants in recent years, it is imperative that China develop hydropower development while adhering to ecological red lines, improved quality control, and strengthened supervision and management.

China has become a world leader in hydropower engineering technology, but faces challenges, including limited exploitable hydropower resources and increased difficulty in development. Though China ranks the first in the world in the number of dams built and installed hydropower capacity, and leads in dam design and construction, challenges remain in this field as well. China has increasingly stringent engineering safety and quality requirements, and more demanding tests for construction safety and operating risks. Some of these changes relate to the gradual shift of hydropower construction into regions with more complex geological and climatic conditions.

As new hydropower projects gradually shift to upstream areas, the average investment per MW of new hydropower is expected to be much higher than that of those already built or under construction in the same river basin. Given increased development difficulty, rising construction and transmission costs, migrant settlement expenses, and environmental protection costs, the economic competitiveness of hydropower is set to decline.

Optimized dispatch will improve the operational flexibility of hydropower. By optimizing watershed-wide dispatch management and improving forecasts for water flow, seasonal or even multi-year regulation of hydropower will enhance the flexibility of hydropower generation. Similarly, increasing cross-provincial and regional power trading, and efforts by the National Development and Reform Commission to work with local authorities and power companies to eliminate inter-provincial barriers, should result in improved utilization of hydropower. Both have helped reduce hydro curtailment in the Southwest.

8.3 Wind energy outlook

China's wind power capacity leads the world, but capacity additions have slowed in the recent 2 years after a booming in 2015-2016. Both scenarios forecast that wind additions will accelerate, and wind power will become the core of China's power system by 2050, accounting for over 40% of electricity production.

According to China's 13th Five-Year Plan for Wind Power Development, by the end of 2020, the cumulative grid-connected capacity of wind power is expected to surpass 220 GW, of which grid-connected capacity of offshore wind power will be at least 5 GW. Annual wind power generation is expected to reach 420 TWh, accounting for about 6% of the country's total power generation. In 2017 China added 15.03 GW of grid-connected wind, reaching a cumulative grid-connected capacity of 163.67 GW. Offshore accounted for 2.02 GW, or 2.98 GW short of the planned target. In 2017, China produced 305.7 billion kWh from wind, accounting for 4.8% of the country's total power generation, still 1.2 percentage points below the 6% target for 2020.

Figure 8-3 China's grid-connected installed wind power capacity from 2011 to 2017

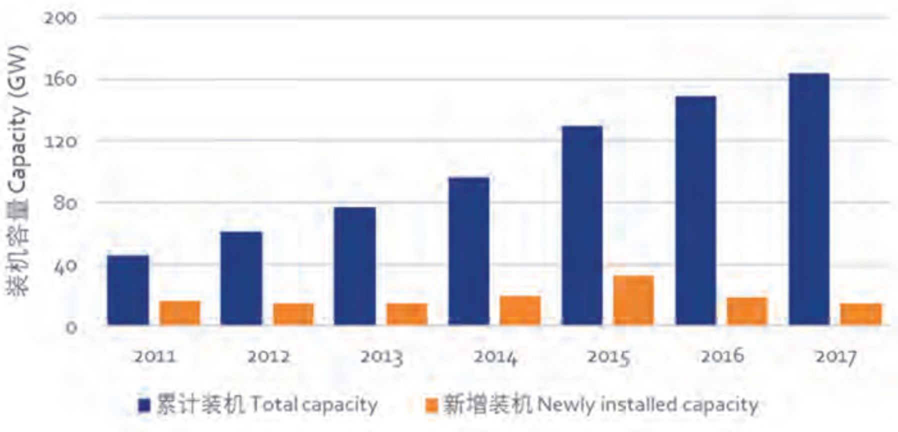
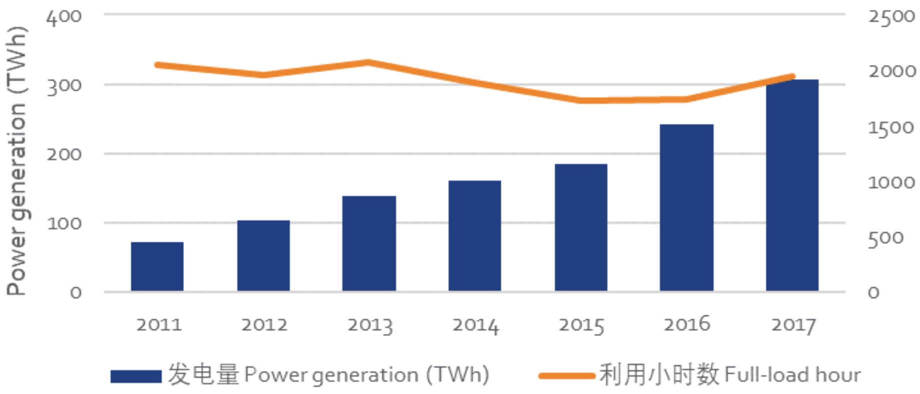


Figure 8-4 China's wind power generation and utilization hours from 2011 to 2017



Policies focus on balancing development and resolving curtailment

China's wind energy policies are focused on balancing regional development, addressing wind curtailment, and promoting market-oriented development of wind power. Since 2011, when China's wind sector began to experience serious curtailment problems, the country has undergone several changes in wind energy policy. Starting in 2016, regions with serious wind curtailment and electricity rationing problems have been temporarily prohibited from adding new conventional wind power construction projects. Wind energy development has gradually shifted towards the central and eastern parts of the country. In 2017, NEA issued the Notice on Relevant Requirements for Accelerating and Promoting the Construction of Grid-Connected Distributed Wind Power Projects, specifies incentives for distributed wind power, and developing low-wind-speed wind farms in the central and eastern regions. In terms of market reforms, China has launched demonstration projects on grid parity of wind electricity. Plants in the demonstration are ineligible for fixed feed-in tariffs, and receive the benchmark price for local coal-fired electricity or the market electricity price. To reduce the cost of wind power, some regions are also studying methods for competitive allocation of wind power, to gradually move toward a bidding approach for electricity prices.

China's present policy and its trend to phase out subsidies for wind is driven by a deficit in funds available for feed-in tariff payments. Policy-makers anticipate ending the FIT for wind power by 2020, and are in the process of considering the subsidy policy for the transition period. The FiT policy may evolve into a fixed subsidy, or that the costs of renewable-energy-generated power be borne by fossil-fuel-based energy sources through a green certificate trading mechanism. Henceforth, market mechanisms such as carbon tax and green certificates will be the major policy direction for developing wind power.

Electricity markets are another key factor affecting wind energy development. China's power market reform is entering a critical period, and several aspects relate to wind power. Tasks include releasing the electricity generation and consumption plans in an orderly manner, setting up a competitive electricity pricing mechanism, broadening the scope of entities directly participating in market trading and the scale of electricity trading, and creating a market-oriented cross-provincial and regional power trading mechanism.

The success in China's power structure transformation is also key to the success of the country's energy structure transformation. China's future power market reform will likely follow the pattern of European and U.S. power markets, in the sense of gradually establishing a spot market that matches the needs of renewable energy sources such as wind power.

Wind development is shifting beyond the Three Norths

Due to wind curtailment and electricity rationing problems, China's wind power development has gradually shifted from the Three Norths (Northwest, North Central, and Northeast China) to the central and eastern parts of the country. In 2017, the Three Norths added 7.24 GW of new grid-connected wind capacity, a decrease of 30% from 2016. This accounted for 48% of the national total, a steady decline in new installation share. With the development of distributed wind farms, the share of wind power development in the low-wind-speed central and eastern regions will continue to grow.

Wind projections depend on turbine size, turbine cost, and resource potential

In China and worldwide show a declining trend, in line with development of wind turbine technology, including a trend towards larger turbines. In 2017, the average wind turbine power of new installations in China was 2.1 MW, 8% higher than the prior year. At the end of 2017, the average size of all wind turbines in China's total fleet was 1.7 MW.

To capture the latest wind power trends, we have adjusted the EDO model to reflect gradually declining costs. By 2030, the investment cost of onshore wind turbine is estimated at RMB 6.8/W, a decrease of 12.8% compared with 2015; that of low-wind-speed wind turbine at RMB 7.6/W, a decrease of 14.7%; and that of offshore wind turbine at RMB 15/W, a decrease of 16.7%. We also assume wind operating and maintenance costs decrease over time: By 2030, the annual O&M cost of standard onshore wind turbine is expected to decrease to RMB 59.3/kW, a decrease of 8% compared with 2015. Low-wind-speed wind turbines O&M costs decrease to RMB 66.1/kW, a decrease of 10%. Offshore wind turbine O&M decreases to RMB 94.8/kW, 8% lower than 2015. From 2030 to 2050, the model assumes only limited declines O&M costs.

Figure 8-5 Investment cost reduction assumption under the EDO model

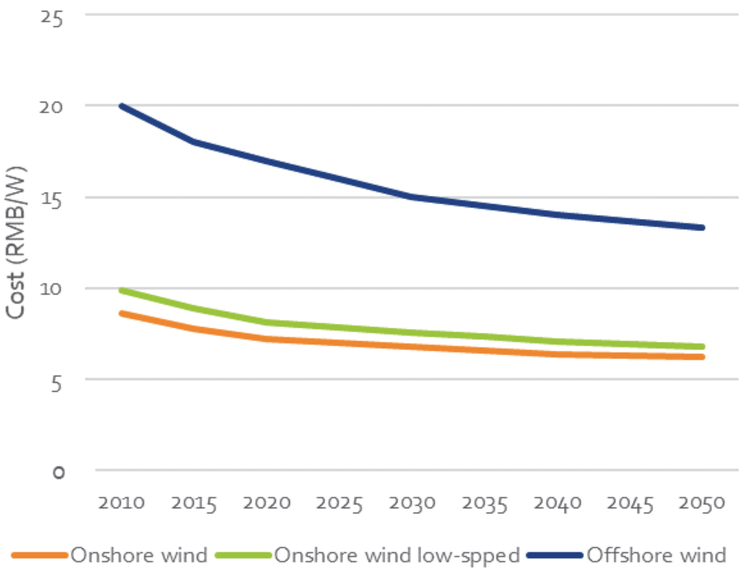
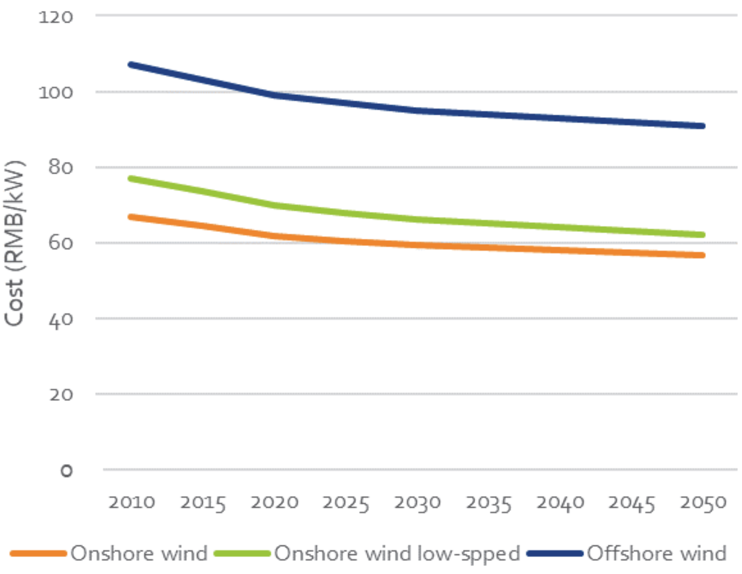


Figure 8-6 Assumption about operating and maintenance cost reductions under the EDO model



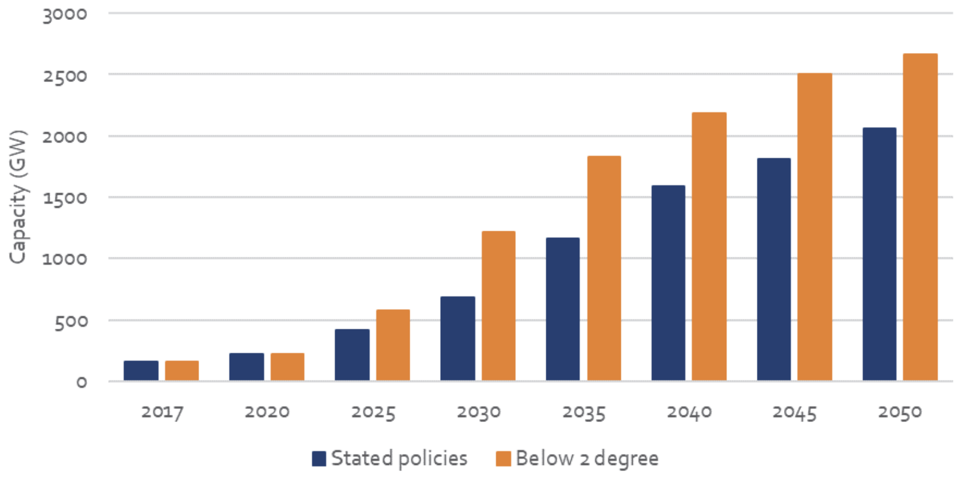
According to the latest wind energy resource assessment, measured at 70 meters above ground China has technically exploitable onshore wind energy resources of 7.2 TW in areas of wind energy density of 150 W/m^2 and above, 5 TW at 200 W/m^2 or above. At 80 meters above ground, China has 10.2 TW in regions with wind energy density 150 W/m^2 and 7.5 TW in regions above 200 W/m^2. Under the EDO model, given such factors as the resource potential of low wind speed regions, and land resource constraints, China's total technical exploitation amount of onshore wind energy development resources is 4.89 TW, and that of offshore wind energy development resources is 217 GW.

Both scenarios show rising capacity, especially through 2030

The Stated Policies scenario, by 2030, projects the installed capacity of wind power will reach 681 GW, including 681 GW of onshore wind capacity (of which 471 GW are low-wind-speed wind capacity) and 10 GW of offshore wind capacity. The main basis for the Stated Policies scenario is China's 13th Five-Year Plan for Renewable Energy Development. Under the scenario where the 2020 targets of 210 GW are met, the model optimizes the wind energy development layout for 2030, taking account of current industrial and grid-connected capacity. To improve the overall efficiency and to avoid wind power from "Three-Norths" to coastal regions through costly long transmission lines, it is of interest to explore the potential of low wind speed (yearly average wind speed lower than 6.5 m/s) regions, with the improvement of wind turbine technology and improved business models for distributed generation. Both scenarios stimulate the development of wind projects in low wind speed regions given a positive vision of the future.

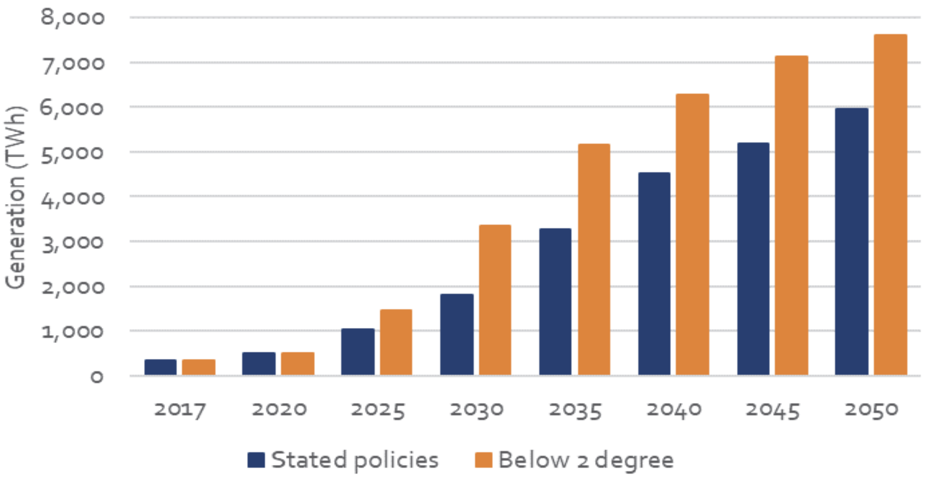
The Below 2 °C scenario foresees rapid development of wind power, enabled by power market reforms, removal of grid bottlenecks, flexible power plant operations, and wind cost reductions. By 2030, the scenario foresees China reaching 1.219TW of installed capacity of wind power. Of this, 1.207 TW represents onshore wind power, of which 1.00 TW comes from low-speed wind. 11.8 GW comes from offshore wind. Wind becomes an important supporting force for meeting power demand, improving the energy structure, and bolstering national economic and social development. Onshore low-speed wind power, in particular, will make the most significant contribution, while offshore wind power expands relatively slowly.

Figure 8-7 China installed wind capacity to 2050 under different scenarios



Under the Stated Policies scenario, by 2030, annual wind electricity generation is expected to reach 1,802 TWh (including 1,773 TWh of onshore wind power). Under the Below 2 °C scenario, by 2030, annual wind electricity generation is expected to reach 3,336 TWh (including 3,300 TWh of onshore wind power).

Figure 8-8 China wind electricity generation to 2050 under different scenarios



The Stated Policies scenario suggests newly installed wind capacity from now through 2030 will concentrate in North China and Southwest where hydro resources are abundant. In contrast, the Below 2 °C scenario suggests further expansion of wind in the main wind capacity provinces identified in the Stated Policies Scenario. In particular, wind capacity will see large increases in Inner Mongolia, Southwest China, and the eastern coastal regions. In 2030, the percentage of exploited resource potential is expected to grow continuously. The Below 2 °C scenario, in particular, foresees the development intensity may climb to 70% or higher in some regions.

Optimized deployment of wind is the most cost-effective way to achieve the goal of holding the global temperature increase to below 2 °C, the EDO model suggests. However, there are a number of uncertainties with this scenario. Realization depends on the pace of power market construction, grid connection of wind power, progress in the construction of other power grids, and the development of supporting industries for the wind power manufacturing industry. Indeed, the results of the Below 2 °C scenario regarding wind also make the current contradictions in wind energy development even more prominent.

Under the Stated Policies scenario, by 2050, wind electricity generation is expected to take up a 43% share of total electricity generation, and the installed capacity of wind power a 36.7% share of total installed capacity. In cases where there are no wind curtailment issues and supported facilities are fully in place in grid construction, wind power development will be mainly concentrated in Inner Mongolia, Hebei, Sichuan, Yunnan and the economically-developed eastern coastal areas. Under the Below 2 °C scenario, by 2050, the installed capacity of wind power is expected to account for 39.10% of total installed capacity, and wind electricity generation to meet 49.6% of electricity consumption. This scenario entails more intense efforts to develop wind energy resources in the central and eastern regions. Wind energy resources in low- and medium-speed wind regions, as well as high altitude areas, are also exploited on a large scale. Under this scenario, wind power will be the largest installation source and occupies the most important position in power structure adjustment.

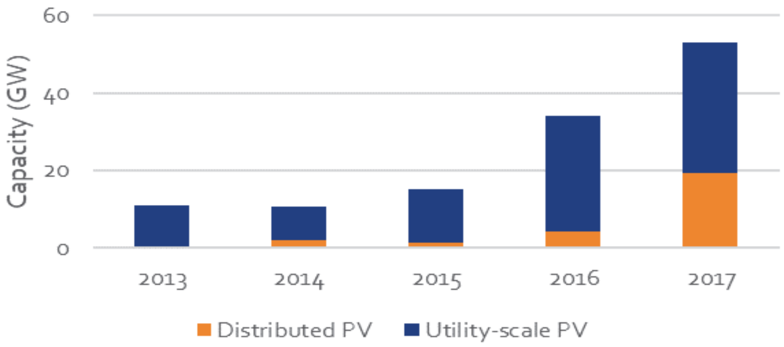
8.4 Solar energy

China's solar PV capacity has grown rapidly in recent years, driven by subsidized feed-in tariffs and cost declines with manufacturing scale-up. In the coming years, China will phase out FITs and focus on developing distributed and centralized solar PV using market prices. As in the case of the wind sector, economic competitiveness and scale-up potential of solar PV depend on full implementation of power market reforms and additional transmission corridors. Both CREO scenarios foresee China adding significant solar PV capacity, reaching 2,165 GW by 2050 under the Stated Policies scenario and 2,836 GW under the Below 2 °C scenario.

China's solar capacity has grown dramatically, but is set to slow

Since the 2013 issuance of State Council's policy promoting solar PV, China has seen annual growth in solar capacity of 65%. By the end of 2017, China had cumulative installed capacity reached 130 GW, comprising 100 GW of central PV and 29.66 GW defined as distributed PV. In 2017, China added 53.06 GW of new PV, an increase of 54% and accounting for 40% of the country's total newly installed capacity of the year. Recently, central PV installations have slowed, with 33.62 GW of new installations nationwide, an annual increase of 11%. Distributed PV witnessed explosive growth, with up to 19.44 GW of new installations, 3.7 times the rate of installations in 2016. The only sector showing tepid growth has been solar thermal power generation, which faces challenging economics: China has just 28 MW of capacity, and currently some 1.3 GW of demonstration plants are planned.

Figure 8-9 : China newly installed capacity of solar PV, 2013-2017(CPV stands for central photovoltaics and DPV stands for distributed photovoltaics)



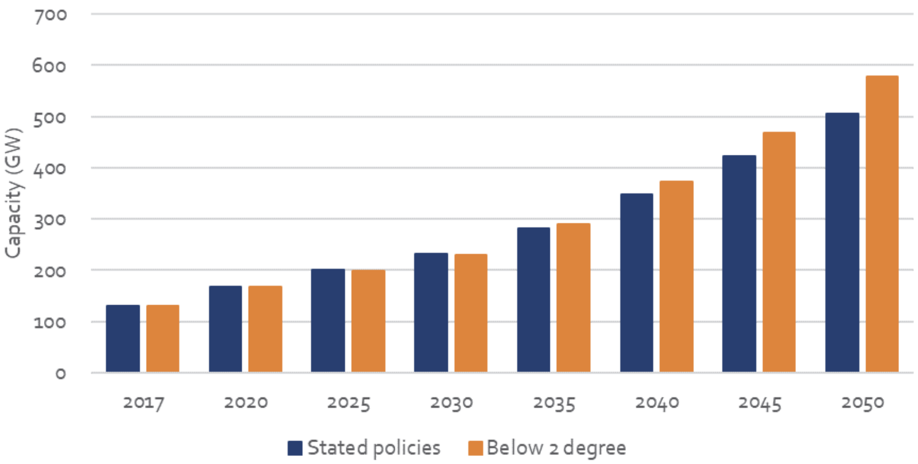
China's solar thermal power system manufacturing industry is at an early stage of cultivation and development. Along the industrial chain of solar thermal power raw material manufacturing, component production, system integration, industrial services and production equipment, China has possessed large-scale production capacity in some fields, such as raw material manufacturing and component production. But other fields, such as production equipment, system integration and industrial services and many areas of solar thermal power, are dependent on government support for projects. In 2016, China identified the first batch of 20 solar thermal power demonstration projects, with a total installed capacity of 1.349 GW. The projects, to be operational by year-end 2018, will receive a FIT of RMB 1.15/kWh (including tax). Judging from the current progress in demonstration project construction, these projects are falling behind schedule, with fewer than a fourth on track for year-end completion.

Policy-makers are phasing out subsidies for electricity from solar PV. Given rapid declines in PV costs, subsidies policy has required changes. The FIT for solar PV electricity has declined for several years, with the latest benchmark on-grid tariffs for solar PV-generated electricity in Type I, II and III resource zones under the FIT scheme have dropped to RMB 0.5/kWh, RMB 0.6/kWh and RMB 0.7/kWh. The subsidy for distributed solar PV electricity has fallen to RMB 0.32/kWh. The current policy trends is to accelerate the FIT phase-out and strictly regulate the amount of new PV capacity granted FIT support. This will affect short-term PV installation growth, but in the medium and long term encourage the industry to reach solar PV power generation grid parity and compete with other power sources. If trends continue, solar PV power generation is set to expand on a large scale.

CREO scenarios project large increase in solar capacity and output

According to the Nation Solar Energy Development 13th Five Year Plan, by 2020, total installed capacity of solar power is expected to reach 230 GW, comprising 150 GW central PV stations and 77 GW distributed PV. Solar thermal power reaches 5 GW. The total power generation from solar power accounts for approximately 300 TWh.

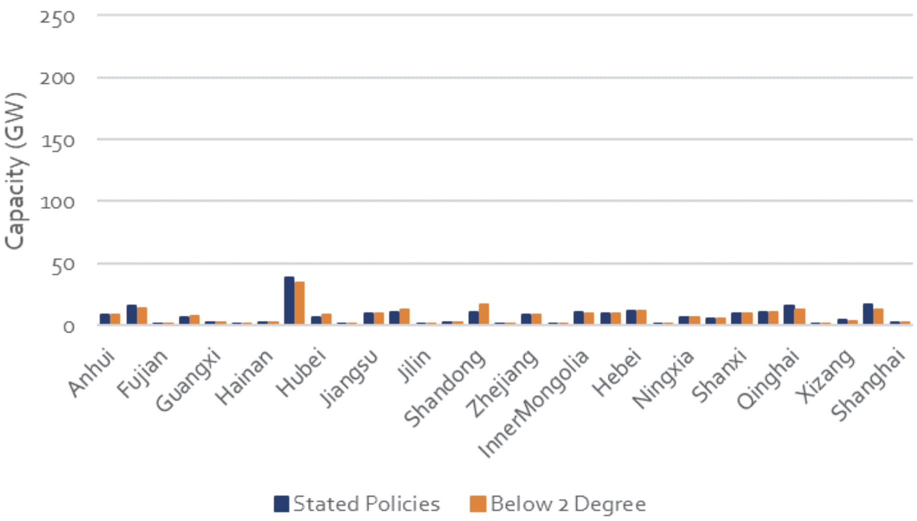
Figure 8-10 Installed capacity of solar through to 2050 under the two scenarios (GW)



The Stated Policies scenario is based on the China's 13th Five-Year Plan for Solar Power Development. In 2017, China's installed solar PV had already surpassed the minimum guiding target of the plan. In 2020, considering relevant policies and further declines in solar PV power generation costs, installations will likely continue to grow, albeit more slowly due to the phase-out of subsidies and limits to FIT quotas. By 2020, we expect solar PV will achieve grid parity in some regions and markets in China. The market size of solar PV power generation is expected to reach 226 GW, with its electricity output amounting to 288 TWh.

Under the Stated Policies scenario, during the 13th Five-Year Plan period, solar thermal power generation basically stays in a demonstration and promotion stage for large-scale power plant application in a bid to foster manufacturing capacity of the thermal power generation industry. Considering the current policies and targets, as well as the progress in the construction of existing demonstration projects, by 2020, the installed capacity of solar thermal power is expected to reach 5 GW, and the electricity output 13.7 TWh. Solar thermal power plants will be mainly located in the central and eastern regions, such as Henan, Shandong and Guangdong, with heavy electric loads.

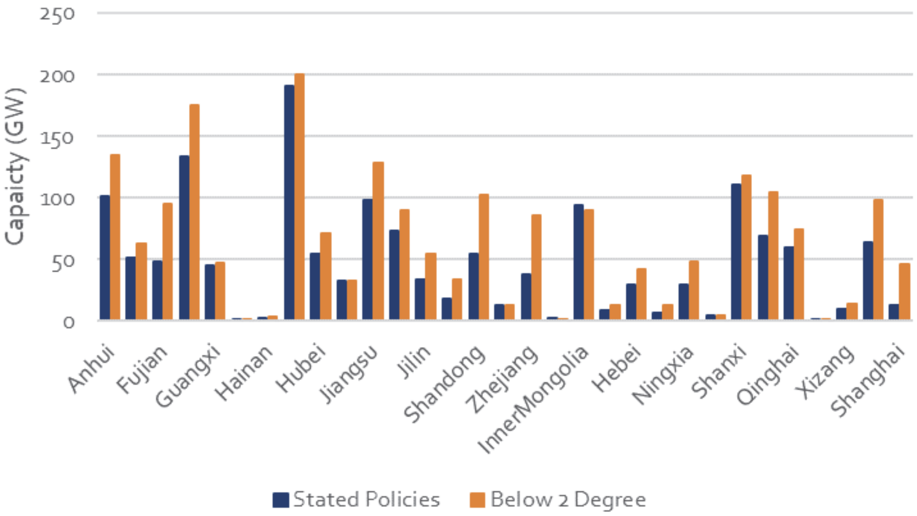
Figure 8-11 Installed solar power capacity by province in 2020 under two scenarios



The period from 2020 to 2035 will be crucial for China's energy transformation. Given China's non-fossil energy targets, the resource potential and economics of solar power, and the expansion of the transmission and distribution system, under the Stated Policies scenarios China will see large-scale development of distributed PV, whereas construction of central PV stations slows. By 2035, the installed capacity of solar PV reaches 1,494 GW, power generation reaches 1,858 TWh, of which 71% comes from distributed PV. Distributed PV will expand rapidly in the central, eastern and southern regions, the central PV station market is likely to slow down in Northwest China, affected by such factors as limited transmission and local power load. The solar PV power generation market will shift from the Three Norths to the central, eastern and southern regions. Driven by increased integration capabilities of solar thermal power generation, and industrial supply chain development, thermal power generation will expand, though limited by relatively higher levelised power cost. Under the Below 2 °C scenario, by 2035, solar PV installed capacity reaches 2,000 GW, and produces 2,480 TWh.

In both scenarios, the installed capacity of solar thermal power reaches 8.3 GW and will remain this level until 2050.

Figure 8-12 Distribution of installed solar power capacity by province in 2035 under two scenarios

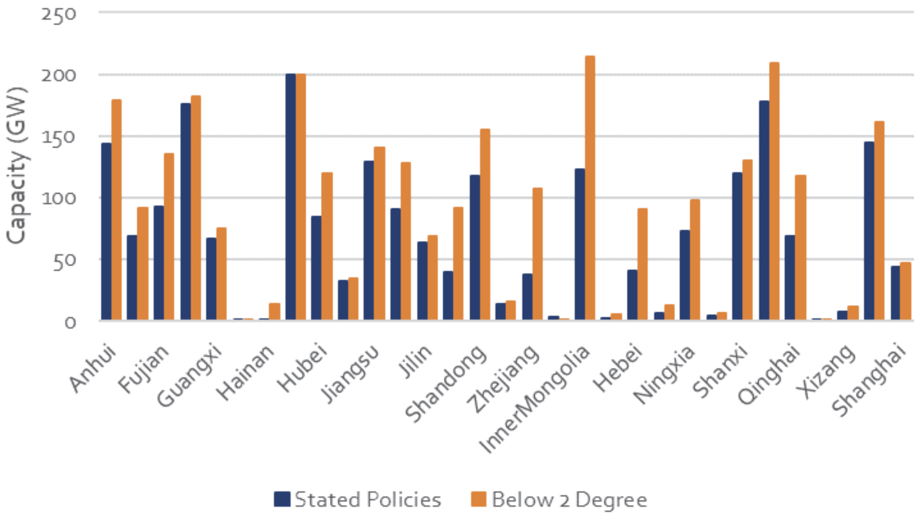


Long-term outlook

After 2035, both scenarios anticipate a high proportion of solar PV, improved solar cost and efficiency, advances in grid technology and storage, and expanded transmission capacity. By 2050, the Stated Policies scenario anticipates the installed capacity of solar PV would exceed 2,165 GW, and solar power production 2,694 TWh.

Under the Below 2 °C scenario, solar power generation expands more rapidly to significantly reduce greenhouse gas emissions. By eliminating grid constraints and renewable integration obstacles, along with other power market reforms, by 2050 solar PV reaches 2,836 GW, with production exceeding 3,524 TWh.

Figure 8-13 Distribution of installed solar power capacity by province in 2050 under the Below 2 °C scenario



8.5 Solar heating utilization

Solar heat also shows potential for strong growth

Most regions of China have abundant solar radiation and are suited for solar heating applications. Its potential depends mainly on heat demand and space for equipment installation. Estimates of China's potential for solar thermal heating resources on analysis of heating demand, building space construction trends, green building trends, and industrial energy efficiency in different Chinese climate zones. Assuming solar thermal is applied to 40% of total building area, the technical potential for solar thermal in buildings will reach 8,500 GWth in 2020.[133] A similar calculation for 2030 and 2050 suggests a technical potential of solar thermal for 2030 and 2050 will both reach 9,100 GWth, or for 13 billion m2 of collector area.

Solar thermal technology is mature and widely used in China, especially for solar water heating, solar heating and solar cooling for domestic and industrial applications. Solar water heaters have a large and active market in China. At the end of 2017, China had solar thermal capacity of 334.5 GWth, or 478 million m2 of collector area, and held over 70% of the world's total cumulative installed capacity. China has a complete solar thermal manufacturing supply chain, with six key industrial clusters in Shandong, Beijing, Jiangsu, Zhejiang, Guangdong, and Yunnan.

Despite its large market, it will be difficult for China to boost solar thermal given recent contraction of demand due to market saturation. Solar thermal mainly serves domestic hot water supply, and has yet to penetrate space heating and industrial or agricultural heat supply markets. In addition, heat utilization integration technology and a system of solar thermal standards are also urgently needed.

Development outlook

The Stated Policies scenario for 2020 is based on the present extent of solar hot water systems, large-scale promotion of solar thermal heating and industrial/agricultural solar thermal systems, and demonstration and popularization of solar-powered air conditioning units. In this scenario, low-and medium-temperature solar thermal installed capacity reaches 512 GW_{th}, or 730 million m^2 of solar collector area. By 2030, as solar thermal heating is applied at scale in industry and agriculture, and as policies promote of solar air conditioning units on a large scale, the installed capacity of low- and medium-temperature solar thermal utilization systems reaches 746 GW_{th}. By 2050, solar thermal is widespread in all three areas of solar hot water, industrial and agricultural heating, and air conditioning, reaching 1,241 GW_{th}.

Under the Below 2 °C scenario, solar thermal application expands from domestic hot water supply to industrial hot water, building heating, and district heating. By 2020, solar thermal capacity reaches 713 GW_{th}, by 2030 it reaches 1,202 GW_{th}, and by 2050 solar thermal reaches 2,411 GW_{th}.

8.6 Biomass energy

Biomass energy is a critical aspect of building a beautiful China. China has issued several important new policies on biomass energy in late 2017 and 2018, clarifying the direction of industrial development. However, due to resource constraints, biomass power and CHP face limits. The two CREO scenarios forecast biomass power capacity to rise from 15 GW in 2017 to over 50 GW in 2050, mostly from waste-to-energy and straw-fired CHP. The scenarios also project near-term increases in bioethanol and biodiesel production.

China's policies support biomass energy, particularly for clean heating

The government has adjusted biomass energy planning targets to more accurately reflect the industry's situation and identify the future direction of the industry. After China's tighter restriction on household coal burning, in January 2018, NDRC and NEA jointly issued Guiding Opinions on Promoting the Development of Biomass-based Heating, listing measures for accelerating the industrialization process of biomass-based heating and replacing coal-fired heating on a large scale.

By 2020, the installed capacity of biomass-based combined heat and power (CHP) is expected to exceed 12 GW, and the total heating capacity of biomass energy will reach nearly 1 billion m^2 of floor area, saving about 30 million tonnes of coal per year. The policy sets a target of having 200 towns, 1000 villages, and a number of medium- and small-sized industrial parks converting to biomass-based heating. The policy calls for preferential treatment for biomass-based CHP projects from the national renewable energy tariff surcharge subsidy funds. Several some county-level biomass-based heating demonstration projects will be launched in the Northeast, and North Central China, and in the "2+26" key cities in the heavily polluted Beijing-Tianjin-Hebei airshed. A number of industrial biomass-based heating demonstration projects will be organized in southern regions. These efforts aim to accelerate adoption of biomass energy in clean district heating, while fostering the overall development of the biomass energy industry.

In January 2018, NEA issued the Notice on Carrying out Biomass CHP Clean Heating Demonstration Projects in Selected Counties, aimed establishing biomass clean heating models. The policy puts in place a production and consumption system for distributed clean heating, featuring local raw material collection, processing, heat production, and consumption. This should substitute for county-level loose coal, by having 100 or more counties and villages, along with a number of medium- and small-sized industrial parks, that are mainly dependent on biomass-based CHP and clean energy heating. It should provide a basis for exploring how to fully switch to CHP in biomass power generation, and improve related policies.

As green and low-carbon development has gained acceptance, China has strengthened clean energy mandates and environmental protections, which in turn has affected biomass power generation. Current policy considers agricultural and forestry biomass CHP key for to upgrading the agricultural and forestry biomass power industry during the 13th Five-Year Plan period. Given its social and environmental benefits, biomass CHP is set to play a crucial role in air pollution control and sustainable urbanization.

Modern biomass energy has grown steadily, led by waste-to-energy

At year-end 2017, China had 15 GW of grid-connected biomass power capacity. Biomass power generation consists mainly of direct firing of agricultural and forestry biomass residues, waste incineration, biogas firing and gasification. In 2017, the installed capacity of waste-to-energy facilities grew 25% to reach 7.3 GW, surpassing direct firing of agricultural and forestry biomass residues. This reflects urbanization, growing municipal solid waste collection, and rapid growth in waste incineration capacity.

Direct-firing of agricultural and forestry biomass residue saw slower capacity growth, due to higher input prices and challenging economics. Installed capacity of this category grew 19% to 7.2 GW in 2017. Landfill gas and biogas power plants and industrial-agricultural organic waste gas and biogas power plants reached roughly 500 MW capacity. Biomass gasification power generation has not yet been promoted on a large scale.

CREO forecasts depend on projections of biomass resource potential

Building on the analysis of CREO 2017, this year's analysis systematically evaluates factors affecting biomass resources, assumptions and methodologies for assessing China's biomass resource potential in CREO2018, and reinforces the scientific and theoretical basis of relevant data sources and calculations.

Municipal solid waste (MSW), including domestic garbage, mainly originates from households and service industries. The composition of MSW is complex and diverse, consisting of recyclable, non-recyclable, and organic wastes. Organic waste includes food waste and wood waste such as disposable chopsticks, which usually refers to MSW mixture that is non-recyclable or can be used in the energy sector, or any pre-sorted organic waste. The MSW resource data in CREO2018 includes only MSW mixture, but sorted organic waste may influence the total quantity and energy density of MSW mixture. CREO statistics on MSW are based on historical MOHURD data on MSW. For projections, urban population and household consumption are the main variables for calculating the amount of MSW available for waste-to-energy.

Waste sorting is considered as an important task for waste disposal in China's 13th Five-Year Plan. 60% of MSW in China is organic waste.[134] The country's goal is to achieve a 35% MSW recycling rate by 2020[135]. It is estimated that 57% of organic waste in MSW will be effectively collected[136]. This rate is used for waste prediction for the period from 2020 to 2050. The calorific value of MSW in China is generally low. In 2016, the calorific value of Chinese MSW is set at 8.2 GJ/ ton, which is derived from three recent cases. With organic matter separated, calorific value will increase and ash content further reduced. It is estimated that by 2050, the calorific value of MSW will reach 10.3 GJ/tonne.

The 13th Five-Year Plan sets the 2020 targets by province for MSW treatment and ratio of incineration-based power generation, which are aimed at setting the minimum application amounts of MSW in the fields of power generation and heating. Some provinces already surpassed the 2020 targets in 2016. In these cases, the 2020 projection is based on the actual situation of 2016. We assume the average MSW development ratios of 2035 and 2050 are 75% and 90%, respectively. Due to progress in waste sorting, the amount of waste available for incineration is likely to decline. However, increases in calorific value and energy amount will ultimately lead to an increase in the amount of available MSW.

Figure 8-14 MSW Resources Available for Waste incineration Power Generation

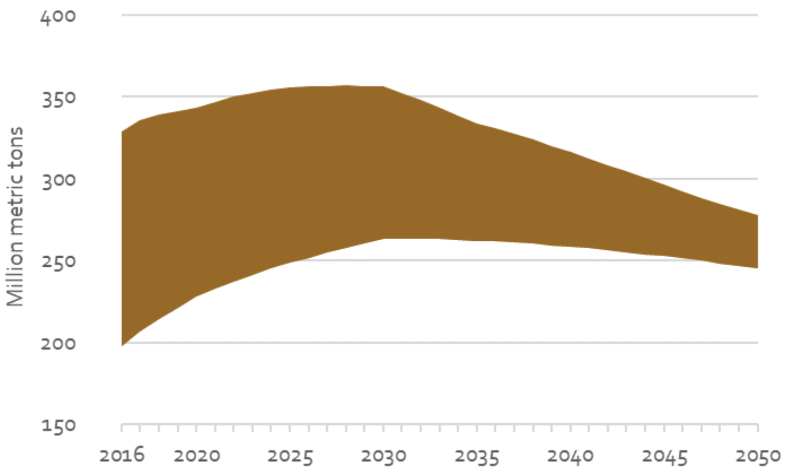
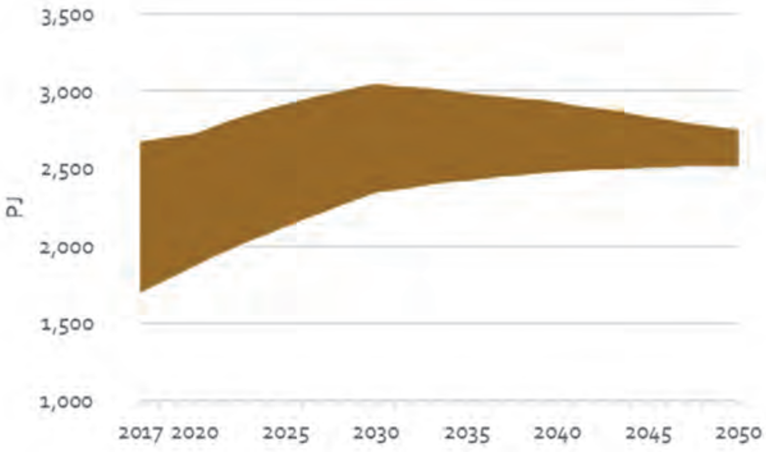


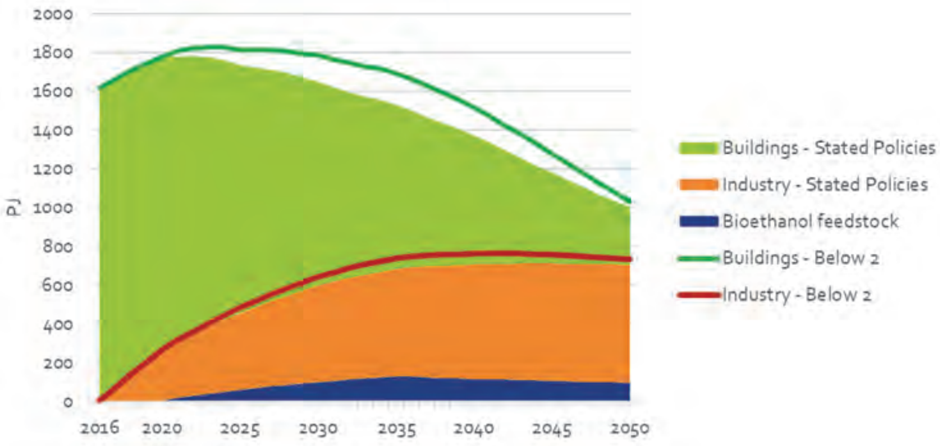
Figure 8-15 The Amount of MSW Energy Available for Waste Incineration Power Generation



By calculation method and usage, agricultural residue resources are categorized into the following several segments: theoretical resources, collectable resources and resources available to use in the energy sector. Theoretical straw resources are calculated based on food crop yields by province. Agricultural residues are calculated based on planting area and crop yields of corn, rice, wheat, beans and potatoes.

Agricultural residues used in end-use sectors (building heating, industry, or used as biofuel raw materials) are the total amount of available resources as shown in the input power generation and district heating model. Agricultural residues used as biofuel raw materials are the same under both scenarios; agricultural residues used in buildings and industry are higher under the Below 2 °C scenario than under the State Policy scenario. Agricultural residues of 2015 are used as the base number.

Figure 8-16 Agricultural Residues Used in Terminal Areas



Biofuel raw materials

Some agricultural residues are used as raw materials for bioethanol production. Stale grains, waste oil and energy crops used for biofuel production are also included. Under both scenarios, stale grains are the main raw materials for biofuel ethanol production. Ethanol production is greater under the Stated Policies scenario.

Figure 8-17 Bioethanol fuel output by raw material

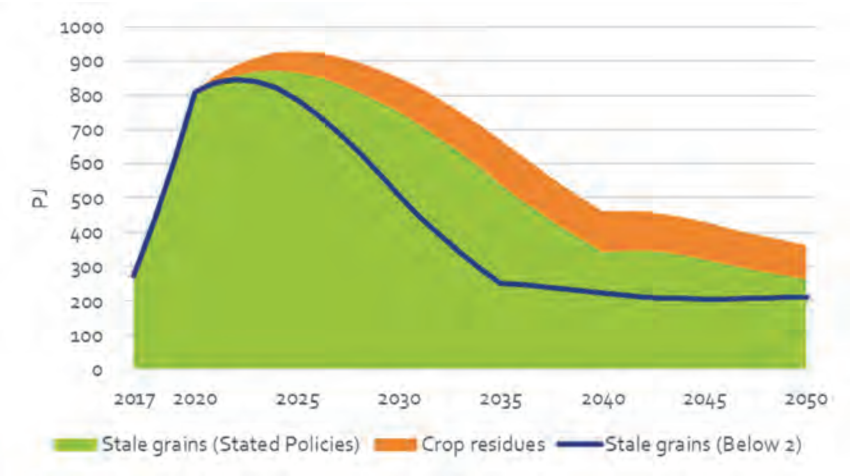


Figure 8-18 Biodiesel output

Timber resources are mainly derived from forestry residues from logging and wood processing.[137][138]

Table 8-2 Forestry residues available for use as an energy source

UNIT	2012	2020	2050
TCE	10,000,000	11,000,000	18,000,000
GJ	293,000,000	322,300,000	527,400,000

As of the end of 2017, grid-connected installed capacity of agricultural and forestry biomass power generation, which is the main utilization method for biomass power generation in China, reached 7.14 GW, accounting for about half of the country's total installed capacity of biomass power generation. 94% of China's direct-fired agricultural and forestry biomass power capacity is in North, Northeast, Central and East China, where crop stalks are abundant. Southwest China, accounting for 5% of capacity, has scarce crop straw, unsuitable terrain, and poor climate for storage. Northwest China lacks straw and has no direct straw-fired power generation. Starting from 2018, newly-added agricultural and forestry biomass direct-fired power generation projects will all be CHP projects.

In 2017, cumulative grid-connected installed capacity of waste-to-energy power plants reached 7.29 GW. With the deepening of urbanization, the focus of waste-to-energy project development has gradually shifted from large- and medium-sized cities to emerging cities. Waste-to-energy power generation will be a key growth point for the biomass power generation industry during the 13th Five-Year Plan period. Waste-to-energy projects are mainly concentrated in East and North China, especially in the relatively developed eastern region, which accounts for nearly half of the country's total installed capacity of waste-to-energy power plants.

Biomass power under the Stated Policies Scenario

Agricultural and forestry waste power will reach 28 GW in 2020. From now until 2020, any project with favourable conditions should transform towards CHP power generation. After 2018, all new projects will be CHP projects.

Waste-to-energy power capacity will grow rapidly. The installed capacity of biogas power generation will remain at around 2 GW from 2021 to 2040, then gradually decline to 1 GW.

Figure 8-19 Installed capacity of biomass by technology through to 2050 under the Stated Policies Scenario

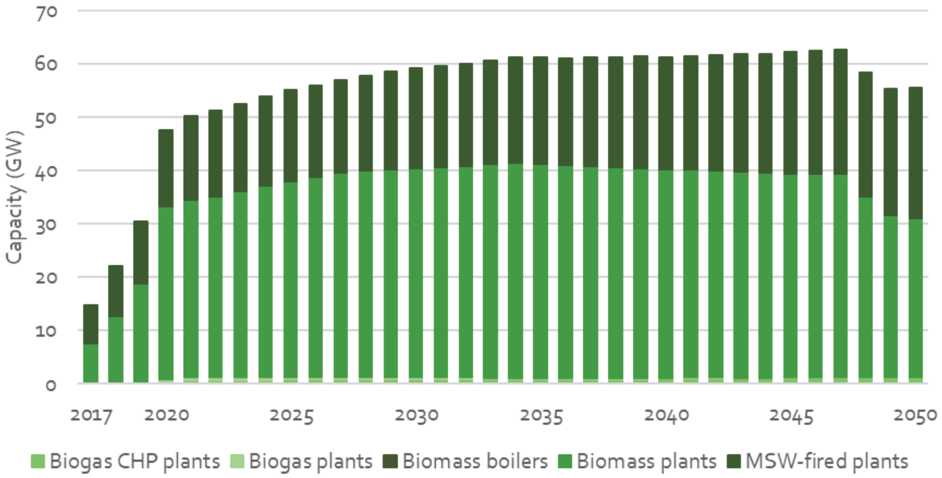
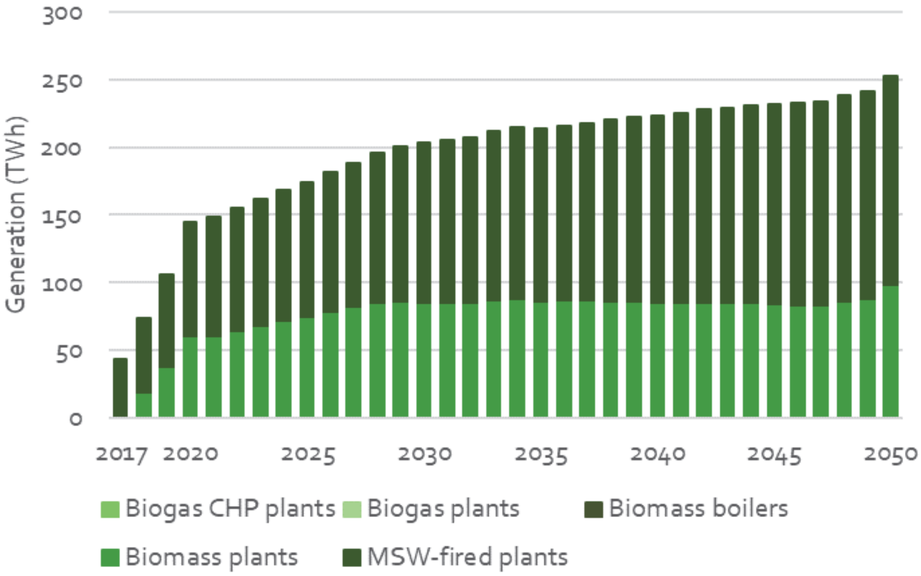


Figure 8-20 Electricity of generation of biomass by technology through to 2050 under the Stated Policies Scenario



Biomass power projections in the Below 2 °C scenario

The Below 2 °C scenario for biomass power shows similar results to the Stated Policies scenario: the installed capacity of direct-fired biomass power generation systems shows little growth while the trend of such projects transitioning to CHP continues. Policies support biomass and coal-fired hybrid power technologies (including CHP) replacing coal to reduce greenhouse gas emissions. Our analysis shows that biomass under this scenario shifts from power generation to biogas and biofuel for industry and transport, due to technology advances and constraints in biomass resources—though the shift is modest.

Figure 8-21 Installed capacity of biomass by technology through to 2050 under the Below 2 °C scenario

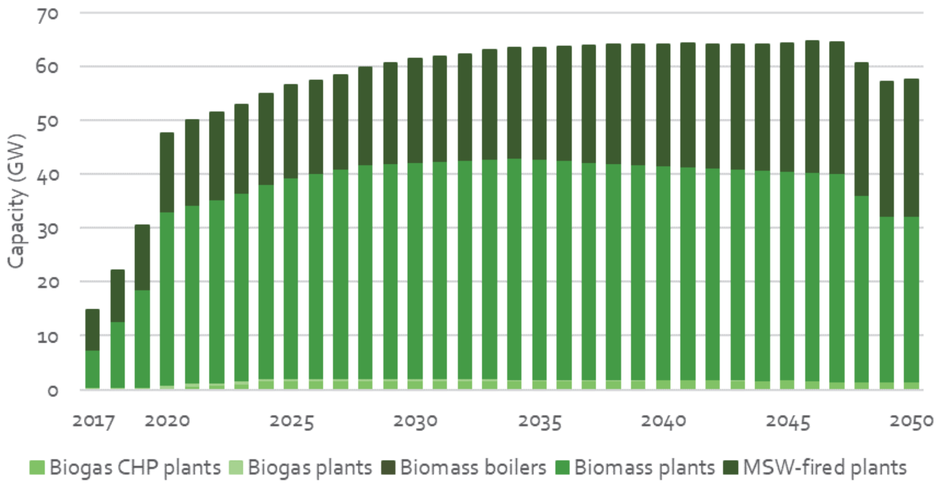
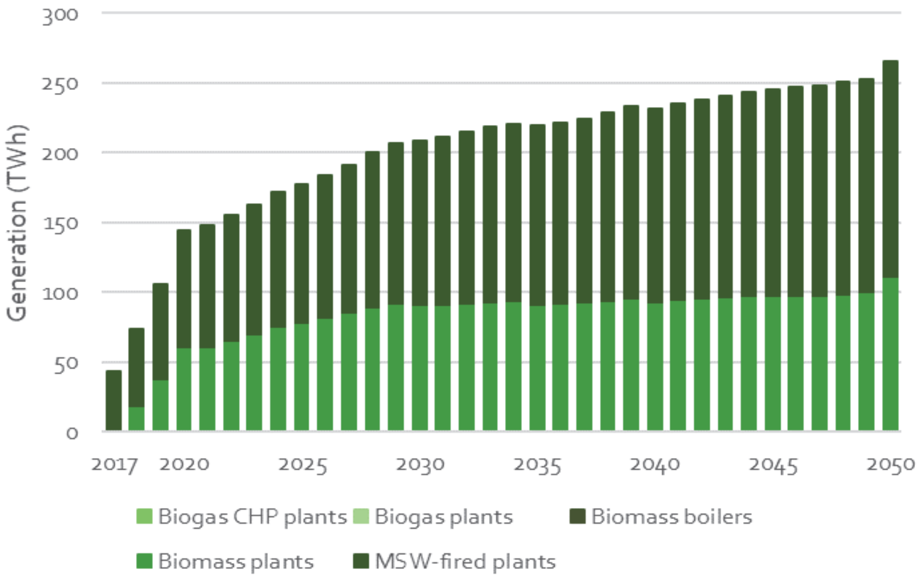


Figure 8-22 Electricity of generation of biomass by technology through to 2050 under the Below 2 °C scenario



9 Energy storage outlook

Energy storage has a major role to play in China's future power sector development, including pumped hydro, grid-scale battery storage, as well as through orderly charging of the millions of electric vehicles that are projected to enter the transportation fleet in the coming decades. The role of storage is particularly critical as wholesale spot markets evolve with high penetrations of wind and solar. Such markets will see declining prices for energy, but rising prices for balancing and ancillary services, accentuating the value of storage of all kinds.

9.1 Spot power markets will increase the value of storage

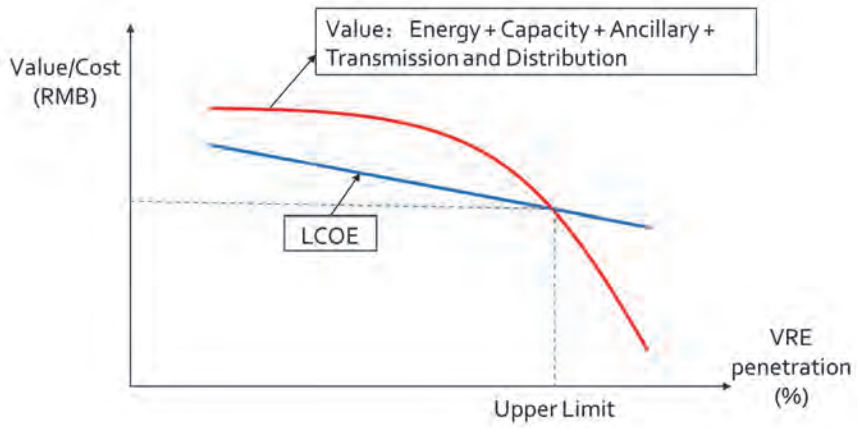
The value of system flexibility, including energy storage, will be high in a power system with high penetration of variable renewable energy. This value could be reflected in by a well-designed market mechanism. In the typical energy-only spot power markets, power sources are bid into the spot market according to their marginal variable operating costs. Wind, solar, and hydro power have lower operating costs, and are therefore first in the merit order, followed by CHP, conventional coal plants, and then natural gas power. Steady increases in the share of wind and solar pushes conventional coal and natural gas plants out of the mix, resulting in lower spot market electricity prices on average, all other things constant. However, with the increased share of variable renewable energy, flexible resources will have greater value to the market. There is also a huge potential for flexible regulation to meet system balancing requirements—even when renewable energy only takes up a small share. Increasing invariable renewable energy will require new flexible resources such as demand response, energy storage, and pairing of multiple complementary energy sources.

Compared with peak shaving on thermal power, there are higher flexible regulation costs associated with these approaches. In the case of a high proportion of renewable energy, the price thus formed at the new supply-demand balance point will be relatively high. In other words, in a future high-proportion renewables-based power market, the trend of flexible pricing will be quite evident. The overall cost of electricity supply will also be determined jointly by electric energy and flexible costs. Compared with the current power supply costs, its economic efficiency will depend on the proportion of renewable power generation, the decline in investment costs of renewables, the decline in the cost of flexible resources such as energy storage, and greater utilization of multiple, complementary energy sources.

Figure 14 shows the value of renewable energy and the Levelized Cost of Energy (LCOE) of renewable energy, as well as changes as a result of increase in the proportion of renewables . The LCOE falls significantly due to lower investment cost as a result of scale - up. With the increase in the proportion of renewable energy, the difficulty of meeting demand at peak hours will also increase. At these periods, renewable energy has a lower overall value to the power system. The intersection of value and cost is the theoretical penetration limit of renewables-based power generation. Thus, beyond this threshold, lower investment costs do not result in increased penetration rate for renewables.

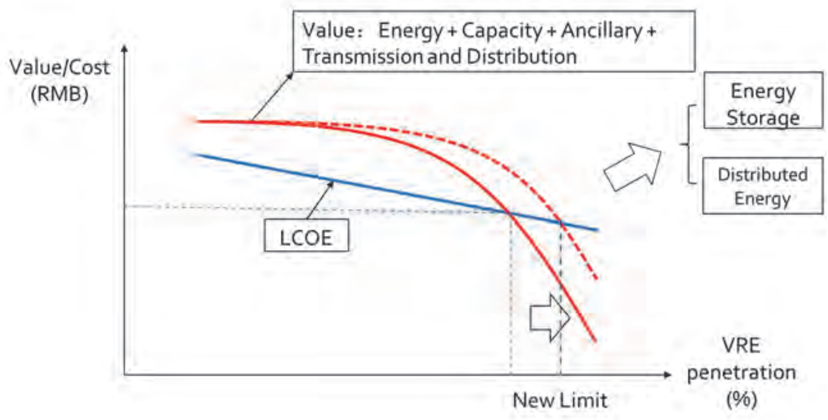
Raising the proportion of renewable energy depends on improving its system value at the margin by improving flexibility, with energy storage as one option. Storage can reduce the slope of the value curve and enable higher proportion of renewable energy (Figure 14).

Figure 9-1 The value of renewable energy in the systems gradually decreases.



Energy storage, along with demand response, can offset the decline in the marginal value of wind and solar in systems with a high proportion of renewable energy systems. Storage contributes to more flexible and schedulable supply of renewable energy by increasing the value of renewable energy flexibility to compensate for declines in the value of its generation capacity and ancillary services. Storage can also help reduce the transmission and distribution costs associated with long-distance delivery of traditional central renewable energy plants by promoting distributed renewable energy. Energy systems based on distributed energy paired with energy storage, or distributed energy paired with complementary energy sources, can enable high proportions of renewable energy.

Figure 9-2The role of energy storage on improving renewable energy value



9.2 Pumped hydro and battery storage both have roles to play

Pumped hydro dominates current energy storage

As of June 2018, China had 30.64 GW of energy storage installed, ranking the first place in the world. Pumped hydropower capacity accounted for the vast majority. Electrochemical (battery) energy storage projects had 470 MW, just 1.6% of the total, compared to 30 GW of pumped hydro. 16 pumped-storage projects under construction in 11 provinces. Three projects are in Guangdong, the province with the largest pumped-storage capacity under construction in China. Hebei has two projects under construction. According to the Guiding Opinions on Improving the Regulating Capability of Power Systems issued by NDRC and NEA, by 2020 the installed capacity of pumped storage power stations will reach 40 GW.

Battery storage economics are improving

For electrochemical energy storage, lithium-ion batteries are currently the main approach in China. Battery manufacturing scale-up have reduced the investment costs of batteries. In early 2018, the cost of nickel-cobalt-manganese ternary lithium (NMC) battery systems were RMB 1.4-1.5/Wh, lithium iron phosphate (LFP) battery systems were RMB 1.45-1.55/Wh, and lead carbon batteries were RMB 1/Wh. Rising battery demand has almost doubled cobalt prices since 2017. The rising costs of upstream materials and the phase-out of downstream subsidies have forced battery companies to accelerate reductions in manufacturing costs.

The Guiding Opinions on Improving the Regulating Capability of Power Systems jointly issued by China's NDRC and NEA in February 2018 proposes accelerating energy storage R&D, particularly lithium-ion batteries, sodium-sulfur batteries, lead carbon batteries, liquid flow batteries, and compressed air energy storage. The document targets construction of large battery energy storage stations of 10 MW and above higher in areas with peak load and frequency regulation demands and wind and solar curtailment issues. The policy targets deploying five 100 MW-level battery energy storage power plant demonstration projects in the Three Norths, pilot projects on energy storage to support wind and solar generation, incentives for distributed energy storage applications, and completion of various new storage technologies for different applications by 2020. The policy sets a 10 MW, 4-hour minimum energy storage capacity requirement for the six provinces with ancillary service markets or energy storage compensation measures, and a 2 MW, half -hour energy storage requirement for China Southern Power Grid.

Currently, domestic commercial electrochemical energy storage projects are mainly focused on price arbitrage based on differences between power system frequency regulation and load-side peak-valley electricity prices. Both of these cases depend on the price and policy environment: For example, energy storage frequency regulation depends on power ancillary service policies. Due to recent disputes in localities, revisions were made to the two Detailed Rules. Energy storage is incorporated into the administrative rules; in the meantime, incentives are given to adopt a market-based mechanism for provision of ancillary services.

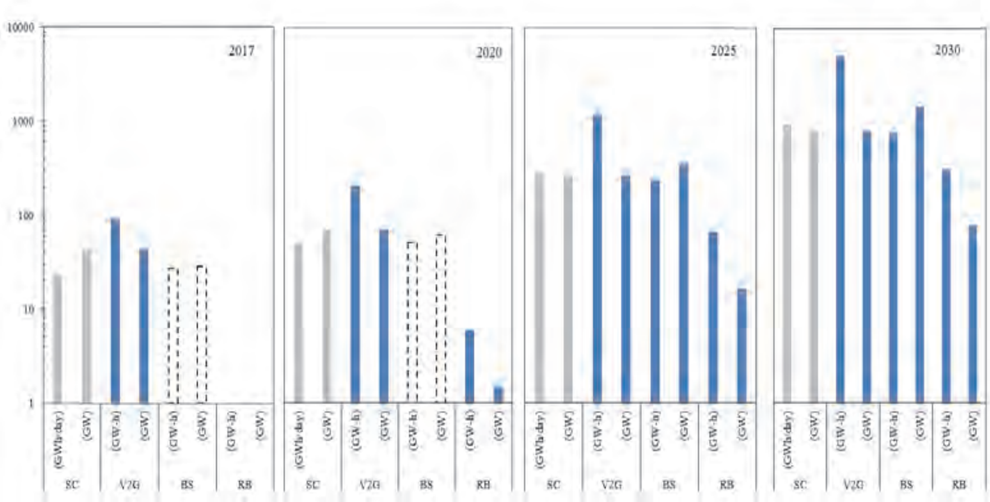
Judging from the current implementation, peak regulation ancillary services is progressing relatively quickly – for example, in Northeast China, Shandong, Shaanxi, Fujian, Xinjiang, and Gansu – while in contrast, the market mechanism for frequency regulation ancillary service lags, with Shanxi as the only province with full implementation. Although some regions propose to include energy storage as one of the main business for peak regulation ancillary service market entities, there are very few commercial projects using battery energy storage for system-level peak regulation.

To summarize, electrochemical energy storage technology is now commercial for backup power supply and UPS. Battery energy storage has also been commercialized to address peak load in some areas with large peak-valley electricity price differences and frequency regulation incentives, and where policies promote reducing demand charges. Energy storage facilities have been built for new energy power plants, mostly still in the demonstration stage. The market for household solar PV energy storage and integrated charging-discharging-storage station is still small, and its future growth depends on declines in energy storage costs.

9.3 Electric vehicles have significant storage potential

Electric vehicles have potential as decentralized energy storage. For several years, China has lead the world in EV sales and total vehicle stock. In 2017, the country sold 777,000 new energy vehicles (including all-electric and plug-in hybrid vehicles), more than half of total global sales. By September 2018, 730,000 new energy vehicles have been sold with 80% year on year increase.[139] Through such methods as orderly charging, vehicle-to-Grid (V2G), battery swapping, and decommissioned battery energy storage, large amounts of electric vehicles could be used as distributed energy storage systems providing considerable flexibility resources for the power system, thereby effectively improving the power system's ability to absorb variable renewable energy sources . Figure 17 illustrates the theoretical energy storage potential from EVs from 2017 to 2030 in four pathways: smart charging, V2G, battery swap and retired battery for storage. It shows based on the 100 million EV stock in 2030, the total energy capacity from V2G would reach 5TWh, which could significantly enhance the intraday grid integration of a large scale of renewable energy under Below 2 °C scenario.

Figure 9-3 Potential Energy Storage Capacity from Electric Vehicles



Development trend of energy storage under the Stated Policies Scenario

Energy storage technology is an indispensable flexible resource in the future renewable energy system. Currently, there are many storage technologies, each with unique features, and complex scenarios for storage application that depend on factors such as energy density, power density, charge and discharge speed, round-trip efficiency, cycle life, and response times. Matching technologies to suitable uses throughout the power and transport sectors requires comprehensive comparison of storage economics, market requirements, storage technical capabilities, and energy system scenarios.

The energy storage deployment in 2050 depends on the overall layout of renewable energy and energy consumption. Under the Stated Policies Scenario, the scale of application of various energy storage technologies depends mainly on the downward trend of the cost of energy storage technologies. Energy storage is commercial for pumped storage, lead-acid batteries, and lithium-ion batteries, while others have been partially commercialized or demonstrated and verified in compressed air, flywheel energy storage, flow batteries, and supercapacitors. The research and development of new energy storage technologies such as liquid metal batteries, aluminium-air batteries, hydrogen storage, and other relative technologies are advancing rapidly. Large-scale energy storage primarily employs pumped hydro and lithium batteries.

This study assumes that, under the Stated Policies Scenario, electric vehicle energy storage is mostly achieved through ordered charging. The scenario assumes China develops all potential pumped storage and hydropower resources suited for pumped storage. The scenario anticipates that central and distributed energy storage using lithium batteries will be developed to a certain extent. The study employs a learning curve to forecast energy storage cots based on cumulative installed capacity and corresponding cost data from China.

Table 9-1 System cost of energy storage technology in the Chinese market

(RMB/kWh)	2012	2013	2014	2015	2016	2017
Lithium Ion Battery	6,000	4,000-5,000	3,000-4,500	2,000-3,000	1,600-2,500	1,600-2,200
Lead Carbon Battery	1,500	1,300-1,500	1,200-1,400	1,000-1,300	900-1,300	800-1,200
Flow Battery	-	7,500	4,000-5,000	3,500-4,500	3,500-3,900	3,500-3,800
Compressed Air	8,000	6,500-7,000	5,000-6,000	4,000-5,000	3,500-4,000	2,000-3,500

Pumped storage energy has the lowest investment cost at RMB 770/kWh. The cost of lead carbon batteries is slightly higher at RMB 900 /kWh. The costs of electric vehicle power battery and lithium- ion battery for energy storage are comparable at RMB 1,550-1,600 /kWh. However, lithium-ion batteries have declined rapidly, from RMB 5,000/kWh in 2012, or eight times of the investment cost of pumped energy storage at that time.

Given present learning rates, greater space for production growth, and rapid growth of EV production, we project lithium- ion batteries to be the lowest cost among all kinds of electrochemical storage in 2025. The system cost will reach RMB 0.4/Wh by 2030, on parity with pumped storage. After 2050, the cost of pumped energy storage will trend upward due to resource constraints and other factors. Lithium battery technology will make a gradual transition from silicon carbon cathode materials for all-solid-state lithium ion battery to lithium metal cathode and sulfur/oxygen anode materials for all-solid-state lithium battery. Lithium-ion technology still has ample room for improvement in performance parameters such as energy density.

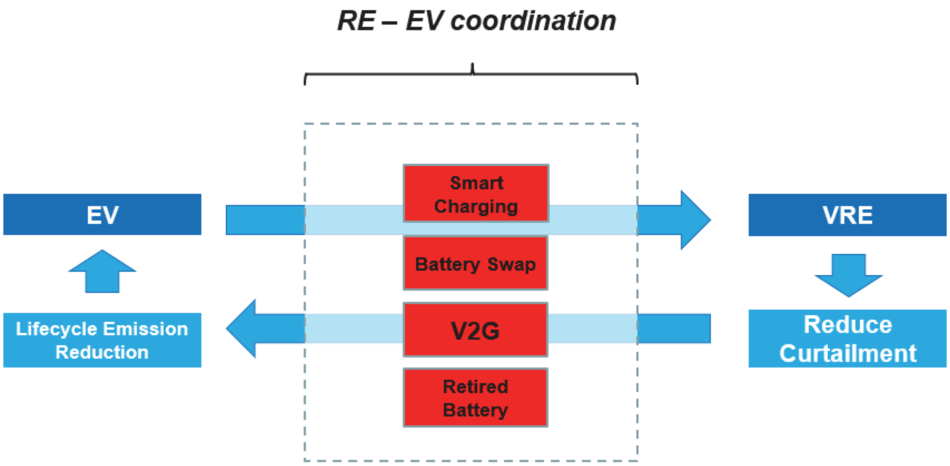
Table 9-2 System cost of energy storage technologies in the Chinese market

(RMB/kWh)	2020	2030	2050
Technical line	**Liquid electrolyte**	**All solid state**	**All solid state**
	NCM, NCA with high-nickel content, graphite cathode-silicon cathode	A solid -state electrolyte (polymer, sulfide, oxide) + **silicon carbon cathode**	**Silicon carbon cathode -** lithium cathode: LiS, LiO2
Performance parameter	cell 400 Wh/kg, system 300 Wh/kg	cell 500 Wh/kg, system 350 Wh/kg	Above 800 Wh/kg, system above 500 Wh/kg
	DoD 80% 3000 cycles	DoD 80% 4000 cycles	DoD 80% 5000 cycles
Cost reduction	cell cost RMB 0.8 /kWh, system cost RMB 1 /kWh	cell cost RMB 0.3 /kWh, system cost RMB 0.4 /kWh	-

Development trend of energy storage under the Below 2 °C Scenario

Under the Below 2 °C scenario, due to further increase in the scale of variable power supplies such as wind and solar power generation, diversified application of energy storage is an apparent option in addition to pumped storage and lithium battery energy storage. In terms of power storage for electric power system, both fixed energy storage power stations and distributed electric vehicle energy storage will play an important role. Among them, pumped storage resources will be fully developed, and pumped hydro storage capacity will reach over 150 GW, storing 1.2 billion kWh annually. Under this scenario, by 2050 China will have over 400 million EVs, with battery capacity over 30 TWh. EVs can realize the energy storage effect of power systems through orderly charging, battery swapping, V2G and decommissioned battery energy storage. Enhanced system flexibility will also expand the scale of renewable energy acceptance at the power generation side and reduce electric vehicles' own life cycle emission levels. In addition, lithium battery energy storage power stations and pumped hydro stations will also help provide peaking resources for short and medium periods.

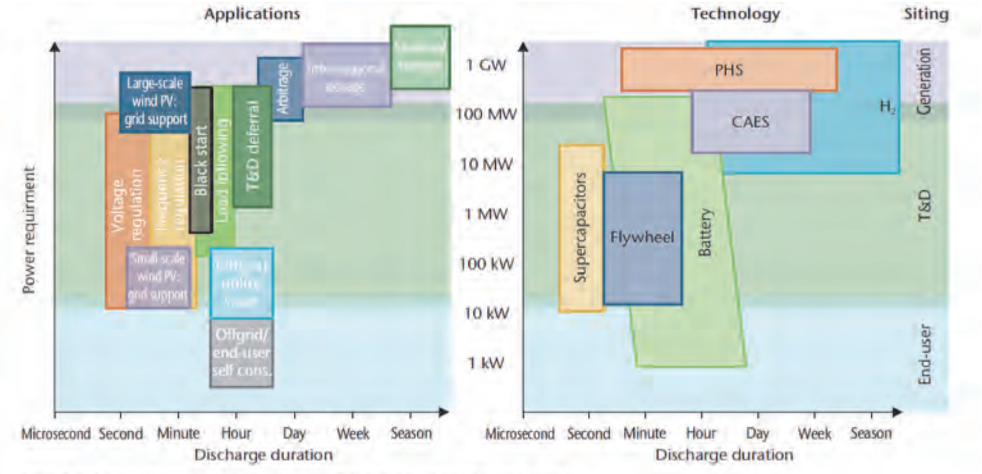
Figure 9-4 Energy storage method of electric vehicles



Under the Below 2 °C scenario, seasonal peaking demands increase, therefore, the policy of a balanced energy mix and hydrogen storage become important seasonal adjustment methods for the energy systems.

Figure 9-5 Figure Features and application scenarios of various energy storage technologies

Source: IEA, Technology roadmap: Energy Storage



Note: CAES = compressed air energy storage; PHS = pumped hydro energy storage.

9.4 Hydrogen develops for supplying industry from clean energy sources

Although hydrogen energy excels at the advantage of long-term energy storage, there also exists the issue of low energy conversion efficiency. As shown in Figure X, especially in systems based on renewable energies, the problem of low conversion efficiency is particularly obvious. This flaw diminishes resulting from the fact that the energy value falls with a higher proportion of renewable energies and the flexibility value is much higher than the energy value. However, as noted earlier, energy system with a high proportion of renewable energies feature low energy prices, which further penalizes storage technologies with low round-trip conversion efficiency. On the other hand, the flexibility value of hydrogen is high, potentially making up for these weakness of hydrogen energy storage.

In addition to time-levelling resources, the policy to adopt a balanced energy mix becomes the ultimate means to improve flexibility. The current energy network is mainly composed of the power grid, the heat network and oil and gas pipeline networks. Since different energy networks have different types of primary energy are not mutually inter connect ed, energy optimization is often carried out independently in their respective networks. With fuel cell technology, hydrogen energy can be converted between different energy networks, converting both renewable and fossil fuels into electricity and heat, or utilizing hydrogen fuels generated through reverse reaction to replace fossil fuels or conduct energy storage, thus realizing collaborative optimization among different energy networks. Hydrogen can be combined with carbon dioxide to integrate the energy and chemical sectors through syngas to achieve optimization in a greater scale. Therefore, a balanced energy mix is a necessary energy operation pattern to realize the high proportion of renewable energies in the future, just the same as energy storage. The Below 2 °C scenario assumes electric vehicle energy storage (including battery swapping and V2G) and hydrogen energy storage potential are fully developed.

Part 3: Policy Research Themes

10 Renewable Energy Support Mechanisms

10.1 Summary

China's policies for supporting wind and solar are changing quickly as the country shifts from fixed-support mechanisms based on feed-in tariffs to more flexible, market-oriented approaches, including auctions and renewable obligations:

- China is currently working on policies that will set renewable obligations for each province based on the present state of renewable development, the renewable potential, and local electricity demand characteristics.
- China is also working to reform subsidies for renewable energy, which will include auctions for onshore wind and solar PV, and relatively fixed tariffs for energy sources like biomass and ocean energy that have yet to reach scale. Price competition will be a central element of ensuring subsidies can be phased out while continuing to promote wind and solar capacity growth.

In addition to describing these changes, other market reform measures are essential to enabling renewable energy to compete without subsidies. These include:

- reforming transmission pricing to prevent cross-provincial transmission fees and cross-subsidies from impeding export of renewables,
- adopting distribution grid reforms favourable for developing distributed renewable energy,
- reforming tax structures (including carbon and land taxes) to reflect external costs of various energy sources, enabling renewable energy (including distributed energy) to participate in spot markets as well as medium- and long-term power markets,
- and promoting green finance to support development of clean energy in place of fossil fuels.

The chapter concludes with a review of international experience with renewable energy auctions, particularly emphasizing the case of wind and solar auctions in Germany. Germany's auctions have featured strong participation, good project realization rates, and steadily falling prices for winning bids. Key factors in Germany's success include transparent procedural steps, a regular schedule for conducting auctions, regulatory stability to ensure bidders and project financiers have confidence relevant rules will remain in place, and emphasizing technology-specific tenders to ensure steady industrial development. The chapter concludes by describing the characteristics of present auction policies in China and their future development.

10.2 Background on renewable energy incentives in China

China is in the process of revolutionizing energy production and consumption, with includes increasing the supply of clean and green energy, as well as improving its proportion in energy production and consumption. China's current target is to increase the proportion of non-fossil energy in the energy consumption to 15% by 2020 and 20%

respectively in 2030. In 2017, China released policies that put sustainable development of energy under the framework of the country's ecological civilization strategy and energy system reforms, proposing to establish an economic system that features green, low-carbon, and circular economic development.[140] The policy outlines plans to accelerate the improvement of the quality and efficiency of energy system development. Promoting and ensuring high-quality energy development is important criteria for near-term energy policies.

To meet these guidelines, the renewable energy industry will need to address some past imbalances and develop in a more orderly manner. This will entail technological advances, industrial upgrades, and elimination of various soft costs to achieve competitive prices for wind and solar energy. It will also require increasing the consumption of renewables and resolving hydro, wind, and solar PV curtailment.

10.3 The renewable electricity quota system

Background

In recent years, China's renewable energy industry has developed rapidly, with renewable capacity dominates new power additions. The bottlenecks for renewables has shifted from technical barriers to market and institutional constraints, especially difficulties obtaining grid access and final consumption.

To address these issues, in 2016 China began to implement the renewable energy target guidance system, which sets a target proportion of renewable energy consumption for each province according to its renewable energy resources and level of energy consumption, as well as the proportion of renewable electricity consumption to total electricity consumption. The target guidance system has helped address renewable energy uptake, but its overall impact has been limited.

Based on international experience and China's renewable energy situation, combined with the trend of power market reform, China will need to adopt a market-based renewable obligation to give renewable energy a long-term role in energy consumption and space for further growth. In March and September 2018, the National Energy Administration issued two rounds of consultation drafts on renewable electricity quotas and related assessment methods. The quota assessment policy will become China's mechanism to ensure market space and long-term development of renewable electricity.

Renewable obligation framework and key issues

The most important features of the quota mechanism are binding and mandatory. Based on the Renewable Energy Law, according to the non-fossil energy ratio requirements and energy development plans put forward by the Central Government, the lowest proportion of the total renewable electricity consumption and non-hydro renewable electricity consumption to the total power consumption of the provincial administrative regions (quota indicators) will be set on an annual basis, considering national and regional renewable energy consumption and energy planning. The State Council will monitor, evaluate, and assess the quota completion annually.

The bearers of quota obligations include provincial grid companies (under State Grid Corporation of China and China Southern Power Grid), local grid companies, power distribution companies with distribution network operation rights (including incremental distribution network enterprises with social capital investment), independent electricity sales companies (without the right to operate the distribution network or undertaking the guaranteed power supply service), the power consumers who participate in direct power trading, and the industrial enterprises that own captive power plants. Other relevant government departments, power generation enterprises and power consumers are not included as compliance entities, but rather coordinate with the compliance entities to implement quota obligations.

A system of renewable electricity certificates will ensure compliance. To effectively measure utilization of renewables, provide a market for balancing generation and utilization among regions, and promote renewable consumption, China will introduce a certification system for renewable energy to support the renewable obligation.

The renewable electricity certificate is a carrier for recording and measuring the production, consumption, and trading of renewable energy. The quota obligation entity submits the certificate of full specified amount as the only evidence for completing the renewable energy quotas. In the initial stages, the main purpose of certificate transactions is to promote renewable consumption through market incentives. Corresponding design elements—for example, agreement transfer, one-way listing, and other renewable electricity certificate trading mechanisms, as well as quota compensation—can also help price formation for renewable certificates. All of these depend on market-based transactions for price formation. The level of renewable energy subsidies per kWh of production can decrease, eventually eliminating subsidies.

10.4 Adjusting renewable electricity prices and enhancing innovation

In the 2015 power sector reform Document #9 and subsequent supporting measures, China proposed to reform electricity generation, transmission and distribution, and retail electricity sales. Power price reform involves all three of these fields. In the past three years, renewable energy prices have yet to align with reforms of the power sector. In particular, wholesale electricity prices still do not reflect the environmental benefits of renewable energy. This has weakened the economic competitiveness of renewable energy. In the near term, China should adjust the price mechanism for renewable energy to reflect environmental benefits.

Adjusting prices at the power generation will promote price formation by market competition. China is gradually eliminating electricity price subsidies for wind, PV and other technologies as the renewable market matures. Based on the results of the first subsidy-free onshore wind power pilot projects in 2017, China will implement subsidy-free wind power pilot projects, expand the scope and scale of the pilots, and eventually carry out subsidy-free central and distributed PV pilot projects. Competition will decrease the cost of onshore wind power and PV. According to the results of these subsidy-free pilot projects and competitive electricity pricing, wind electricity prices and subsidies will decline on an annual basis. For PV, prices will decline in stages based on technologies, utilization modes, and regions. In contrast, China will continue to set relatively stable prices for renewable energy technologies still scaling up, such as concentrating solar power (CSP) and offshore wind, and biomass power generation which shows little change in costs and depends on agricultural environmental protection policies.

Various market reforms are needed to ensure renewable integration across larger regions; these include dynamic adjustment of the transmission prices, lowering the transmission and distribution (T&D) prices for cross-provincial transmission, and reducing the policy-based cross-subsidies included in the transmission and distribution prices.

The first round of separately set T&D prices will conclude in 2018. In the future, T&D prices across provinces and municipalities will depend on their actual conditions, require strengthening daily supervision of T&D prices in various regions, and timely adjustment of T&D prices in individual regions. This would benefit from dynamically adjusting transmission prices at each voltage level under the condition that the overall price of electricity stays constant during a supervision period.

Long-term development of renewable energy requires greater transmission of renewable energy from Southwest China and North China to load centres in East and Central China. Currently, the price of transmitting power across regions and related cross-subsidies are too high: receiving provinces thus perceive imports of clean hydro, wind, and solar as uneconomical compared to in-province resources. This represents a major barrier for renewable energy uptake. We suggest prudent reductions in transmission prices for inter-provincial and cross-regional transmission with a certain proportion of renewable energy and electricity distribution and reducing policy-based cross-subsidies bundled in present T&D prices.

Economic policy tools such as pricing can support distributed renewable energy. Innovate in policies and mechanisms, promote the participation of distributed renewable energy in the electricity market, advance the implementation of the models of direct trading and the commission sale of electricity through grid, and establish business models with different characteristics. Provincial pricing departments should set calculation methods of wheeling cost for distributed renewable energy in accordance with provisions of the national reform of T&D pricing, based on government-approved transmission and distribution pricing, considering grid resources, voltage levels, and electrical distance of market transaction parties involved in distributed generation.

Although the standards for wheeling cost have been clearly defined in some parts of China in 2018, there remain unreasonable aspects. For example, Zengcheng, Guangzhou, stipulates that the power transmission and distribution pricing of the provincial power grid (including policy-based cross-subsidies) corresponding to the access voltage level of power consumers will be lowered by RMB 0.02 cents/kWh. As a result, the wheeling cost of distributed power generation for market transactions is still too high, and on the other hand, the wheeling cost of distributed power generated and consumed at low voltage levels is still higher than at high voltage level. Hence, T&D prices for distributed generation and consumption remain distorted. Policy-makers should leverage the results of market trading pilot projects to clarify the standards for wheeling cost in different regions, for different voltage levels and different situations.

We also recommend to eliminate system reserve fees for distributed renewable energy consumers (including micro-grid consumers). In turn, policy-makers should explore the ways to exempt such users from various electricity governmental fund fees and charges, and reduce cross-subsidies that need to be paid based on the voltage level in relation to the scope of supply and consumption. This will enhance the economic competitiveness of distributed renewable energy.

10.5 Taxation that supports renewable energy development

China's current taxation system plays an insufficient role in reflecting external cost. Energy tax levels presently do not fully reflect the external costs and damage to the environment of fossil energies such as coal, whether concerning pricing policies or tax policies. Similarly, taxation policies for clean energies such as renewable energy provide little support for their development and do not reflect their environmental benefits. There are three aspects where taxation policies could bear enhancement: value-added tax for renewables, the flexibility of taxes in areas such as carbon or environmental attributes, and land taxes.

Currently China supports for renewable energy with tax reductions and exemptions on value-added tax, including refunding 12% of VAT upon payment for large and medium-sized hydropower, 50% for wind and solar energy, and 100% for biomass power generation. However, for renewable energies with no fuel costs—excluding biomass, which has high fuel costs, but these are mainly non-taxable and hence non-VAT-deductible—the VAT refund policy only helps alleviate the problem that the actual tax of renewable energy is too high compared with other energy sources. The policy makes the VAT of various energy sources seem relatively fair in terms of tax rate but cannot reflect the encouragement of the production and consumption of clean, renewable energy. In addition, the current policy of immediate 50% VAT refund for solar will expire at the end of 2018, which needs to be addressed as soon as possible.

Second, energy taxes and carbon taxes adopted in many countries can help curb consumption of electricity from high-emissions fossil energy sources. China has yet to establish such mechanisms. Though have had environmental taxes since 2017, this represents the change of a prior environmental fee to a tax, but the level of the tax falls short of the actual environmental costs for the generation and consumption of fossil energy.[141]

Land taxes represent a third area of potential reform. For renewable electricity, many local areas have unclear land policies, irregular implementation of land use and natural resource protection laws, and inconsistent implementation of land taxes and fees. These policies often work in favour of incumbent fossil energy sources—such as existing power plants and mines—and to the detriment of renewable energy sources.

Improved taxation would promote renewable energy. In response to the above-mentioned issues, China could improve the taxation mechanism in the following three areas:

1. Continue the existing preferential tax policy for renewable energy, extend the VAT refund policy for large- and medium-sized hydropower and solar power generation or make a long-term policy, and formulate a new tax reduction policy for the renewable energy industry to reflect greater tax fairness.
2. Further enhance the regulation and flexibility of taxation, accelerate the promotion of carbon emission tax legislation, and increase the collection and scope of environmental and resource taxes.
3. Clarify that land occupied by renewable energy for development will not require urban land use tax, and collect and reduce of taxes and fees on cultivated lands, grasslands, and forest lands in a reasonable manner.

10.6 Power market reforms to promote renewable energy

China should move quickly to stablish a competitive power market and enhance power system flexibility. At present, China's power system still mainly operates in a mode that features the allocation of planned quantity of electricity generated, especially by coal, and the use of inter-provincial and inter-regional tie lines as the basic load units for scheduling. The results of relevant research show that, from 2016 to 2050, these two operational factors increased system cost by nearly RMB 1 trillion. [142]

Establishing a modern competitive power market including spot markets is the central institutional step of the power market reform. There are many forms of effective market models, but they all follow three basic principles: marginal pricing, opportunity cost pricing, and no-arbitrage pricing. They allow for full utilization of zero marginal cost advantage of wind power and solar power generation, thus minimizing power system costs and maximizing social welfare.

China needs to gradually replace the current **planned electricity + direct electricity trading** power operation mode with the **electricity spot market**. China's first spot market pilot projects will launch after 2018. In the market areas with high proportion of variable power sources such as wind power and PV, it is necessary to, combined with the forecast of new energy at the power supply and grid sides, take the lead in launching the day-ahead and intra-day spot markets, and establish a real-time market after accumulating experience. At the same time, China should explore how renewable energy gradually engages in the medium- and long-term trading market and spot market.

China should make efforts to develop ancillary services markets rather than ancillary service compensation mechanisms. The government should also accelerate the exploration of renewable energy participation in long-term, medium-term and spot market mechanisms, establish a power market information disclosure mechanism and develop a timetable for disclosure as soon as possible. By requiring power trading dispatching organizations to publish comprehensive market information including load, supply, network utilization, congestion, early warnings, transaction volume, and prices in time at different stages of the market, China could eliminate information barriers and enable fair and orderly electricity market competition.

To enable a high-proportion of renewable electricity, China should increase the value of the electricity market. The levelised cost of electricity (LCOE) does not fully reflect the time, place, and mode of power generation, whereas the value of electricity to the power market depends on whether the time and place of power generation meets the power demand. This entails consideration of two aspects. One is that a high-proportion of renewable electricity generation necessitates a power market with continually improving flexibility. The power system transformation requires comprehensive measures to improve the flexibility of the entire system. In a flexible power system, variable renewable energy maintains high system value even at high penetration levels. Therefore, it is necessary to accelerate the establishment of modern power markets including the spot power market and the ancillary service market, and propel various power source, load and energy storage facilities to free up flexibility, while increasing the market value of new energy power.

Second, the participation of high-proportioned renewable electricity generation in the power market still requires a low-carbon policy framework. As wind power and solar power generation with zero marginal cost become the dominant power sources and drive down spot market prices, renewable energy must not only improve its own output characteristics to enhance the value of the electricity market but will also require establishment of an additional low-carbon policy framework to embody its social value. This can include mandatory renewable electricity quotas on the retail electricity side and tradable green certificates, and **whole energy spot + medium- and long-term Contract for Difference (CfD)** market based on competitive bidding prices.

Improve the market-oriented investment and fair operation mechanism of incremental distribution network and micro-grid. In the future, distribution network will be at the heart of the integrated production and consumption system of distributed energy, and is developing towards the direction of activation, localisation, synergy, marketization and intelligence. Looking ahead, the power grid will eventually have a network structure characterized by multi-zonal autonomy, interconnected interactions, and supporting multi-energy complementarity on a distributed and flat basis. However, traditional distribution network development models have difficulty meeting the requirements of new technology applications and modern energy service systems. Moreover, grid companies have been responsible for the planning, review and construction of the distribution network all year round, and the government, consumers and other market players have not participated independently. Grid investment is an autonomic behaviour of the grid companies, and the public properties of the grid generally tend to be ignored.

Since 2015, a new round of power market reforms has shifted management of incremental distribution networks to local governments, enabling local grid planning powers to return to the government, and also enabling power development to be more closely integrated with local economic development and energy services. This encourages social capital investment, constructing, and operating incremental distribution networks by introducing competition to break the monopoly, so as to continuously improve distribution service capabilities as well as the energy efficiency of electricity systems.

The Guiding Opinions on Electricity Distribution Pricing in Local Grids and in Expansions of Distribution Networks (No. 2269 [2017] of the National Development and Reform Commission) established that incremental distribution networks have the same market position as local grids and provincial grids, and can participate in fair market competition.[143] Provincial grids should be open to local grids and incremental distribution networks without discrimination. The distribution network should be able to either supply electricity in the region or participate in cross-provincial cross-regional power purchase transactions. Incremental distribution network enterprises and other grid enterprises should enjoy equal rights, including network interconnection rights, operation scheduling rights, power access rights, and market trading rights to promote fair development competition of grids and the optimized operation of multi-energy complementary distributed energy, and develop active distribution networks and micro-grids.

We suggest China combine with the incremental distribution network to establish a distributed power generation market-oriented trading mechanism for local consumption of renewable energy at the distribution network and micro-grid level. We also suggest China establish distributed renewable electricity, heat and gas trading platforms at the distribution network and micro-grid level, truly reflecting the low wheeling cost and high consumer value of distributed energy. We also suggest China encourage distributed energy, electric vehicles, and virtual power plants to participate in the spot market and ancillary service market.

10.7 Ramping up efforts to support green finance

The green financial system is an institutional arrangement that includes financial instruments such as green bonds, green credits, and green development funds and related policies. In recent years, with the increasingly urgent situation of resource conservation, environmental protection and climate change, the voice of developing green finance has been growing, and green finance has attracted more attention from national governments, financial institutions and enterprises. According to the *Bonds and Climate Change: State of the Market 2016* report issued by the Climate Bonds Initiative, the global green bond stock market reached US$ 694 billion in 2016, of which China's green bond market was US$ 246 billion, making it the largest green bond issuing country in the world.[144]

China has carried out some basic work in systematically building a green financial system, actively participating in the development of global green financial rules and taking the opportunity to build and improve a green financial system, which is not only conducive to promoting global low-carbon development, but also allows for its own sustainable development.

To promote green credit, we suggest China should provide renewable energy industry with special low-cost funds and formulate discount policies for the financing of the renewable energy industry by central and local finance authorities. The government should also support financial institutions to increase their credit supply for the renewable energy industry, and channel their resources to financing deadlines and other arrangements.

Second, in terms of green bonds, we suggest that green channels should be open for listed companies in renewable energy, build mature equity and bond financing systems, develop integrated financial services, enrich renewable energy financing tools, and increase the application of green bonds, asset securitization and other offerings. China could explore how to relieve the short-term subsidy payment pressure on renewable energy feed-in tariffs by issuing treasury bonds or corporate green bonds.

Third, we suggest China create and flexibly use various investment and financing models such as government and social capital cooperation and encourage local governments to establish green development funds. Fourth, the government should encourage financial institutions to set up a credit rating and risk management system that is in line with the characteristics of the renewable energy industry and explore financial services such as renewable energy specialization guarantees and insurance.

10.8 Renewable auctions and tenders in China and abroad

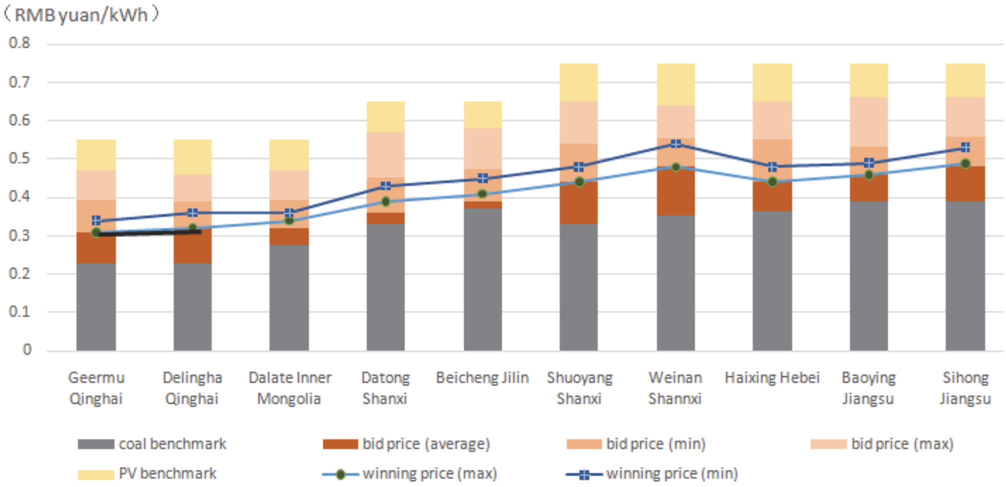
Auctions and tenders in China

At present, many countries apply auction/tender mechanism for pricing renewable energy. China has adopted auctions or tender mechanism at two stages during renewable energy development. The first stage is at the start-up and demonstration stage of market. China used project bidding for onshore wind power projects from 2003 to 2009, for offshore wind power in 2009, and for PV around 2010. At the time, China had few such projects, and lacked reliable cost data or even approximate cost data to support setting FITs or pricing-by-project. Bidding price mechanisms offered a way to discover cost and power price demands. Later, China launched the first batch of CSP pilot projects from 2015 to 2016, with a similar price-setting procedure.

The second stage of auctions and tenders in China relates to the mature stage of large-scale deployment of renewable energy. Power price bidding of advanced technology PV bases in 2016 and 2018 was based on practical experience and historical data. Through bidding, China achieved the goals of maintain the development scale of renewable energy, optimizing grid layout, and developing renewables in an orderly fashion. Auctions also enabled lower realized prices and improved utilization of capital and tariff subsidies. Since 2016, the on-grid tariff for all central PV power plants is determined by competition, implemented by local energy authorities.

Based on the bidding situation of PV at the trial large-scale development stage, renewable auctions have achieved results at multiple levels, producing valuable experience and lessons. The experience of the power price bidding for PV in China in 2016 and 2018 show that the auction mechanism is a good fit for electricity system marketization. Price discovery through auctions has enabled price discovery and reasonable reductions of per kWh subsidies for renewable energy. Third, pricing though bidding can establish a relatively fair competitive environment, which can help the development of competitive enterprises. Finally, establishing a normative order in project development can help optimize the power system's structure and layout.

Figure 10-1: Power price of the third batch of Top-Runner PV bases in 2018



Note: The average tender and bidding price is calculated based on the number of projects, and the grey part for Qinghai represents the starting price of subsidies for renewable energy FiTs.[145]

Tenders for Advanced Technology PV Bases have had a remarkable impact on decreasing power prices. In particular, standardized bidding forms may solve the problems involved in obtaining local government approval on projects, reducing non-standard and unreasonable extra charges applied to PV projects by local departments. The third PV front-runners first carried out the comparison and selection in terms of bases, defining land costs, grid-connected conditions, and local supporting infrastructure conditions and others in advance. In the long run, bidding competition is not only consistent with international development trends but also beneficial to the sustainable and healthy development of China's PV industry.

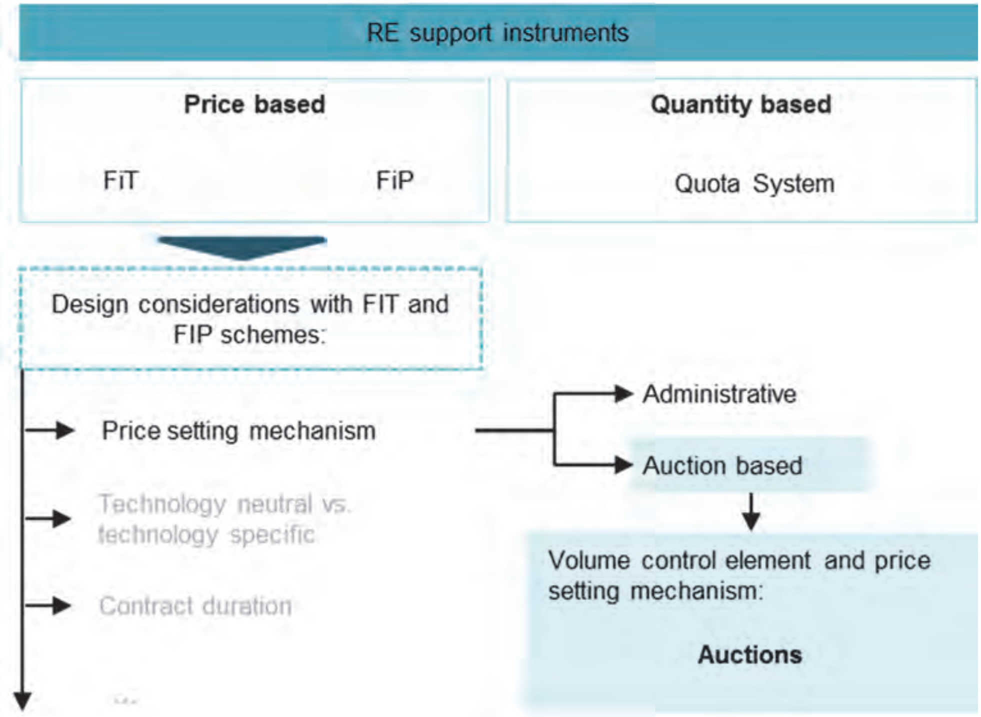
Latest progress of international auction/tender and reference to China

Overview

According to the Renewable Energy Policy Network for the 21st Century, auctions are becoming the preferred support policy for large-scale RE projects worldwide.[146] The number of countries using multi-criteria or pure price-based auctions is increasing rapidly. In 2017, at least 29 countries held renewable auctions. These include design auctions which select the winner only based on the lowest price (pure-price based auctions) and those with multiple criteria in the winner selection process (multi-criteria auctions). The latter are also referred to as tenders.

Auctions can support renewable energy, but auctions themselves are not a support instrument, but rather a design element of the general renewable policy system. For example, Feed in Tariffs (FITs) or Feed in Premiums (FIPs) can provide general support determining the level of support in an auction process to allocate financial subsidies cost-effectively. Other renewable-supporting design elements can include priority feed-in and grid connection guarantees, and these measures will influence the resulting price bids. Figure 10-2 gives an overview of the relation between auctions and other support instruments.

Figure 10-2: Classification of renewable energy support schemes[147]



There are several reasons for using auctions in the context of renewable energy. The main strength of auctions is the increased cost efficiency resulting from direct competition between market participants.[148] Well-designed auctions can provide real-world prices for RE electricity and can help to avoid windfall profits or underfinanced projects. Project developers have more information on expected costs than the government.

Another reason for auctions is that they enable policy-makers to plan and control the overall cost, the expansion rate of renewables, and the energy mix. The auction administrator can either set a budget cap for RE support or an annual capacity cap. Moreover, policy-makers can define auction caps as technology-specific or site/region-specific to determine the energy mix and geographical expansion of RE.

A well-designed auction results in a contract between the project developer and the regulator. This provides transparency and states the commitment and liabilities of each party. The contract offers a secure investment environment for the further project development and increases the commitment to build the project and limits the investment risk. Auctions are flexible in their design and adapts to the underlying circumstances of any energy system. To meet differing requirements and objectives, auctions can combine different design elements.

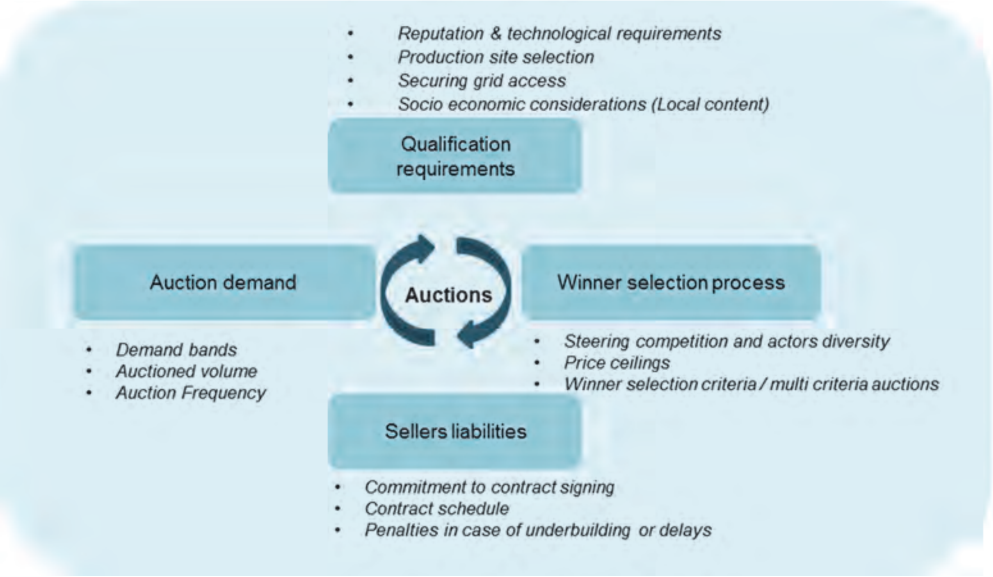
A major weakness of auctions is the risk of underbuilding and delays in the development and construction phase. Competitive bidding can result in over-aggressively low bids unrepresentative of real, underlying prices. Underestimations or too optimistic cost development estimations can have the same effect. This may lead to non-fulfilment of RE deployment targets and potential political consequences. Furthermore, auctions contain relative high transaction costs for both project developers and the auction administrator. High transaction cost can become a barrier to enter the market, particularly for small players. This may reduce competition and creates the risk that a few, dominant players control the market and the auctions bids.[149] Eventually, this can lead to higher-than-necessary price levels and thwart cost-efficiency targets.

The extent to which each of the strengths and weaknesses affects the outcome of auctions highly depends on the auction design.

Elements

Auction elements are listed in Figure 10-3.

Figure 10-3: Auction elements [150]



In order to obtain increased cost efficiency, auctions need sufficient competition. A different price-setting mechanism should be used in case reasonable competition cannot be expected.

The suitable adaptation to the specific situation is also highly relevant. The optimal auction design choices are highly dependent on the policy goals and the current market situation. A comprehensive market research regarding the available technologies, the potential suppliers and the project pipeline should always be the start of the auction design considerations. Moreover, auction rules should provide some flexibility that auctioneers can change the design in case the underlying circumstances change. However, any change in the policy design should be communicated well in advance to provide security for project developers.[151]

An individual and context related auction design is also highly important.[152] Auction design should not neglect the details because these greatly influence the auction outcomes. Policy makers should consider the macro-economic conditions of the country as well as the state of the electricity industry when designing the auction scheme. Furthermore, the interaction between different design criteria and resulting potential trade-offs have to be considered. Policy objectives should be weighed against cost-efficiency and design elements have to be chosen in line with the overall objectives.[153]

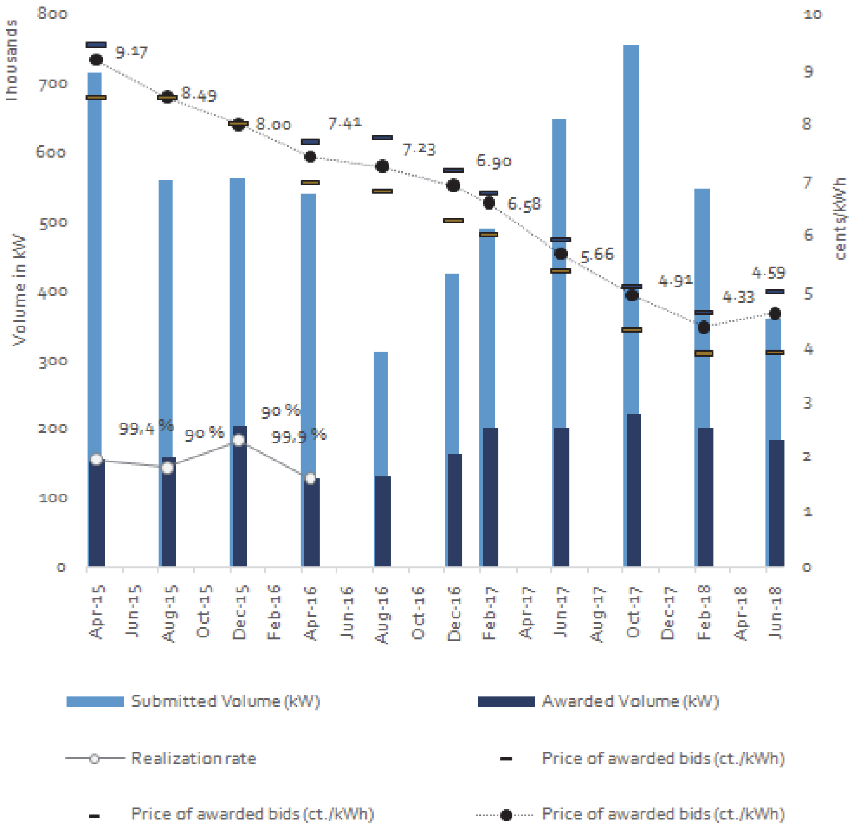
Another key factor of success relates to a clear and well specified communication of auction rules. Auction rules should consider all relevant possible scenarios to avoid uncertainty and eliminate room for interpretation. Auction administrators should inform bidders early and provide them with enough time that bidders can become familiar with the rules. Auction objectives and the operation should be clearly stated prior to the auction procedure itself.

Besides a clear communication of auction rules, regulatory stability is a key element for a functional auction process. Constant changes in the regulatory framework create uncertainties and increase the risk perception by investors.[154] In case changes in the auction procedure become necessary, they should be communicated clearly and well in advance. Empirical analyses also show that a long-term auction schedule with fixed dates increase planning reliability for investors and should be preferred over a “stop-and-go” implementation. Moreover, the auction design should be as simple as possible. A complicated winner selection processes which cannot be retraced by the auction participants afterwards and confusing qualification rules discourage potential bidders.[155]

Auctions in Germany

Auctions for PV in Germany already started in 2015. Figure 10-4 summarizes the auction results from 2015 until 2018. It can be seen that the submitted volume exceeded the awarded volume. In addition, the realization rate of the awarded project is shown in Figure 10-4. So far, statements about the realization rate for PV auction in Germany can be made for the first four auction rounds from April 2015 until April 2016, which lies between 90 % and 99.9 %.[156] Prices decreased from 9.17 cents/kWh in the first auction in 2015 to 4.59 cents/kWh in 2018.

Figure 10-4: Results of PV auctions in Germany [157]



Evaluating the auctions based on the given objectives, the following conclusions can be made.

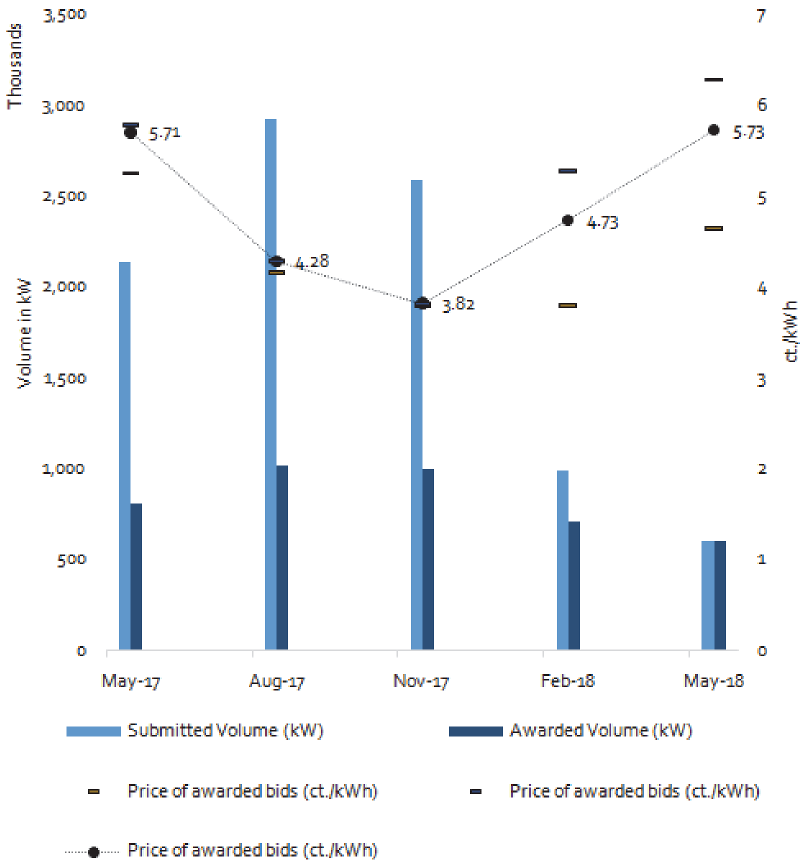
- Controlling and steering the expansion volume: Until now the realization rates for PV projects are relatively high (90 - 99.9 %). This indicates success with regard to volume control. Profound analyses will be possible within the next years, when more data are available. However, the auction results until now seem promising.
- Decreasing policy support cost by competitive price determination: With the competitive bidding in PV auctions, support payments decreased from 9.17 € cents/kWh in 2015 to 4.59 € cents/kWh in 2018. This equals a decrease by 50 % which can be attributed to high levels of competition and decreasing technology cost. Since 2017, agricultural land was allowed in some areas for PV projects which decreased bid prices further
- Achieving a high level of participation: The level of submitted bids in every auction round is significantly higher than the awarded volume. Therefore, it can be concluded that participation and competition is high. However, analyses show that the bids were mainly submitted by professional project developers, the participation of small or community owned projects was rather low.

Since the introduction of auctions in 2017, five auction rounds for onshore wind took place with a total awarded capacity of 4,133 MW. Notable regarding wind auctions are three special conditions in the auction design.[158] First of all, auction participants submit their bid according to the "reference yield model", which means that bids are calculated for one reference location in order to address price distortions by different local wind conditions. Secondly, there are volume quotas for so called "grid expansion areas". These areas where defined because a regional concentration happened in previous years and let to grid bottlenecks. New projects within grid expansion areas are only awarded until a predetermined capacity threshold is reached. Thirdly, privileged qualification requirements were applied for community-owned projects until 2018 (small project developers). This included longer lead times for provision of the permit according to the Federal Pollution Control Act and project realization lead times (4.5 years compared to 2 years for regular projects). The objective of these privileged qualifications requirements was mainly to ensure bidder diversity.

Evaluating the auctions of onshore wind based on the given objectives, the following conclusions can be made.

- Controlling and steering the expansion volume: For auctions in 2017, nearly all of the awarded bids were submitted by community-owned projects. Therefore, the project realization period ends in 2021/2022 which contains a higher risk of failed or delayed realization than the shorter realization period for other bidders. Industry experts estimate that there is a risk of ~30% that the planned projects will not receive approval. Moreover, the third auction resulted in relatively low prices (Euro 0.0382/kWh). It is possible that projects prove to be unprofitable in retrospect and bidders withdraw from the projects.
- Decreasing policy support costs by competitive price determination: Prices decreased in 2017, which was mainly caused by the competitive advantage derived by some project developers from the special regulations for community-owned projects. The risk of winner's curse for the actual project realization is seen as rather high. Prices increased in 2018 because the special regulations were changed.
- Achieving a high level of participation: The privileged requirements for community-owned projects were initially introduced to enable bidder diversity. However, auction results in 2017 showed the very opposite, a high concentration of successful bids in one bidder segment. Representatives of community-owned projects argued that the regulation did not target the needs of the intended target group.

Figure 10-5: Results of onshore wind auctions in Germany [159]



Near-term roadmap of auctions or tenders in China

Principles

In terms of auction/tender form of power price, the pricing is compatible with various power price mechanisms, so both fixed auction/tender power price and auction/tender with fixed subsidies are acceptable. Therefore, China may implement auction/tender pricing in parallel with existing FIT policies, FIT policies which will gradually change in the future, and various economic incentive policies which involves green certificate trading.

Auction pricing of renewable energy generally employs competitive pricing among renewable energy projects with similar technology or various technologies; other non-renewable resource projects are excluded. Therefore, it is feasible to design the auction/tender pricing mechanism only from the perspective of how to promote renewable energy development, optimize the layout of the grid, and develop clean energy at an appropriate pace.

The auction/tender mechanism for large-scale development shall have the precondition that development of renewable energy technology and industry market has reached a certain level. For example, large PV and onshore wind power during the 13th Five-Year Plan period are qualified. It is expected that offshore wind power and CSP will also be qualified during the 14th Five-Year Plan period.

Before the wind and solar energy reaches parity through tenders, the tender can play a role in stimulating technological progress to reduce technical cost and eliminate unreasonable non-technical costs, improving the economic competitiveness of wind and solar. After the general parity is reached, the configuration of items through tender methods is still applicable. Initially, auctions help to lower the FIT, as a natural follow-on to years of supportive policies, wind and solar energy are more affordable, allowing electricity consumers to use cleaner and more affordable electricity. Subsequently, wind and solar energy can also compete in the wholesale or spot market of electricity. Overall, auctions can help China improve the quality of variable renewable energy such as wind and solar energy through adoption of improved technology and equipment.

Implementation path

Since 2016, China has generally implemented tendered configuration items and FIT for PV power plants. In May 2018, the National Energy Administration issued the Notice on the Relevant Requirements for Wind Power Construction Management in 2018, which clarified that for newly-added centralized onshore wind power projects and the offshore wind power projects with undetermined investment entities in the regions and municipalities that have not yet issued the 2018 Wind Power Construction Plan, China should configure and determine feed-in tariffs through competition. For the provinces, regions, and municipalities that have issued their 2018 Wind Power Construction Plan and for offshore wind power projects that have already identified the investment entities, the original plan can be further promoted in 2018. From 2019 onwards, for the newly approved centralized onshore wind power projects and offshore wind power projects in all provinces, regions and municipalities, FIT should be configured and determined through competition. Starting in 2019, the wind power sector will be based on competitive pricing, with the FIT determined by competitive bidding. At the same time, the 2018 Wind Power Project Competitive Allocation Guideline (Trial) stipulated principles to be followed in local wind power tenders and clarifying the specific methods of wind power tenders in the near future. This may also become the basis for tendering other renewable technologies.

There are two categories of competition. The first category is wind power projects with identified investment entities that have signed wind power development agreements with local government and completed preliminary work such as wind measurement evaluation and site survey. This means companies with self-contained project participates in the tender, similar to the auctions used by Germany in recent years for wind power and PV power generation. China will use a comprehensive scoring with price accounting for at least 40%, or use an alternative in which projects are first evaluated technically, then based on price, until the quotas are completed according to the order of the electricity price from low to high.

Evaluation of bids will reflect in six aspects:

1. company capabilities, including investment capability, performance, technical capability, and evaluation of corporate integrity performance;
2. advanced nature of equipment, including wind turbine selection, wind energy utilization coefficient, dynamic power curve guarantee, wind turbine certification;
3. technical solutions, including full use of resource conditions, optimization of technical solutions, utilization of hourly calculations, intelligent control of operation and maintenance, decommissioning and demolition programs, economic feasibility,
4. preliminary work that has been carried out, including overall project planning, wind measurement and wind energy resource assessment, feasibility study design, supportive documents obtained,
5. access and consumption conditions, including commissioning grid companies to analyse access systems and consumption capacity and provide results;
6. declaration of the electricity price by calculating the 20-year fixed FIT under the condition of reasonable income.

Assuming grid connection with guaranteed grid uptake of operating hours, the tenders request price quotations according to minimum guaranteed hours. For hours exceeding guaranteed operating hours, market pricing applies, which is scored based on the electricity price within the minimum guaranteed hours. In terms of the number of tenders each year, provincial energy authorities should adopt a competitive approach to determine the new construction scale for the projects with identified investment entities, in accordance with provincial wind power targets approved by the energy department of the State Council and the total targeted annual new construction. Projects with high overall scores should be prioritized into the annual construction plan in the local region.

The second category is wind power projects (including large-scale wind power bases) with determined investment entities for which local governments have organized the site areas for the preliminary work of wind power development, and then invited provincial power grid enterprises to implement the projects with appropriate power transmission and consumption conditions. The provincial energy authorities shall publicly select project investment entities through competitive means such as tender, taking the qualification for the FIT as a pre-condition. This approach is similar to the offshore wind power tender in Denmark and the project tender of Chinese PV leaders. The basic principles of the competition are the same as described above, but with only four evaluation elements, namely (1), (2), (3), and (6). Pre-work and grid-connected conditions are managed and organized by central or local energy authorities.

Both categories of projects include a FIT as an important condition, and projects with low intensity of subsidies are preferentially included in annual construction plans. In addition, policy-makers have set an electricity price ceiling for tenders, in that the FIT promised by the bidding company should not exceed the wind power benchmark its geographical area. Electricity price accounts for the largest proportion in competitive allocation factors, ranging from 40% to 100%, depending on local conditions and wind power development needs.

11 Renewable energy in power markets

11.1 Renewable energy in power markets

This chapter analyses electricity trading in mature electricity markets, and different approaches for enabling renewable energy to participate in market trading. The chapter also discusses the goals, principles, and progress of China's power market reforms, and analyses the basic conditions, market entities, participation paths, market tools, and risk management measures for renewable energy participation in electricity trading.

Overview of approaches for renewable electricity trading

Competitive electricity markets[160]

Since 1990s, Competitive electricity markets have been operating in the Nordic countries, UK, Germany, etc in Europe and PJM, Texas, New York, California etc. in U.S. The system operators (the independent system operator, regional transmission organization, or transmission service operator) are responsible for running the spot market, consisting of a day-ahead market and intraday market, and the ancillary service market (or real-time balancing market) to address system imbalances. Generators are free to sign over-the-counter (OTC) contracts with electricity retailers or users, usually mid- to long-term on a monthly or longer basis. There are two types of medium- and long-term trading being executed. The medium- and long-term trading employs physical bilateral contracts, and the rest of electricity trading takes place in spot markets. Medium and long-term trading can also employ bilateral contract-for-difference (CFD) financial contracts. Electricity sold in CFD contracts are cleared against spot markets, and all electricity produced by generation companies participates in spot trading.

Approaches for renewable electricity trading

Most countries with relatively large proportions of variable renewable energy currently use bilateral electricity trading. In addition to mandatory grid uptake of renewables and feed-in tariff (FIT) projects, renewable energy generation can participate in the following electricity market trading: OTC, day-ahead market and intraday market (comprising the spot market), and real-time balancing market (part of the ancillary service market).

Renewable energy generators will undergo significant changes in their profitability, revenue prospects and market risks in different market conditions and trading modes.

In many countries, the Power Purchase Agreement (PPA) is currently the main model for renewables to participate in the electricity market. Most renewable energy generators choose to sign a PPA with an electricity retailer to sell their whole power generation capacity to the trading companies. In general, a PPA sets a fixed trading price or a certain price index for the trading. If there is land or roof resources in the same location of the electricity consuming company, it can sign a physical PPA, which basically replicates self-generation and self-consumption.

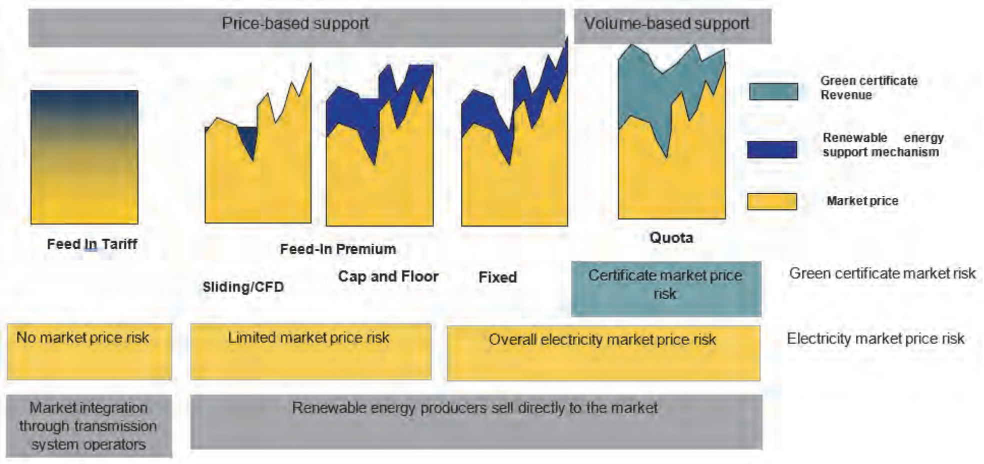
In recent years, there is trend toward large companies directly purchasing clean energy from new energy power generators. According to data from Bloomberg New Energy Finance (BNEF), in 2017 43 companies from 10 different countries signed power-purchase agreements (PPAs) with more than 4.5 GW of wind power or PV. Only a small number of projects are directly controlled by large companies such as Google and Apple, which have electricity market expertise and are registered as participants in the electricity wholesale markets for physical power purchase agreements. Instead, most companies purchasing clean energy employ virtual PPAs. In a virtual PPA, the power purchaser and power generator are often not in the same location but are connected to the same regional grid or electricity market, and power stations sell electricity wholesale to trading centres at local prices. If the PPA price is higher than the wholesale price at the project location, the risk can be greatly reduced, and the profit can be higher.

In Europe, the mechanism for renewable energy's participation in electricity trading is more diverse and undergoing change. Since 2014, Germany has implemented direct marketing for large-scale new energy power stations, and new energy generation has received feed-in premium (FIP) subsidies based on market trading and consumption. New energy developers are usually directly involved in the wholesale electricity market. In the U.K., renewable energy units sometimes participate directly in various medium- and long-term electricity trading, spot trading, and real-time balancing mechanism, and thereby assume the same responsibility and balance mechanism as other generators. To stimulate new energy investment and reduce risks, the U.K. adopted the CFD as a financial contract for renewable generators.

Table 11-1 Models for variable renewable energy participation in electricity trading

Trading mode	Country/state	Trading entity	Power purchase entity	System balance responsible party and approach	Electricity trading price	Incentive/risk control tool (additional income)
PPA	US; UK; America, Middle East, etc.;	New energy power station owner	Utility unit	Utility company participates in spot market	Negotiate or invite bids for electricity	Renewable Energy Certificate (REC)
VPPA	US	New energy power station owner	Business consumer	Owner participates in spot market	TSO/RTO/ISO electricity spot market price (return the overcharge and demand payment of the shortage?)	Renewable Energy Certificate (REC)
Direct participation in the wholesale market	Denmark, Germany, UK	New energy power station owner	TSO/RTO wholesale market	Owner participates in spot market	TSO/RTO/ISO spot market price	FIP/CFD
Mandatory acquisition (guaranteed acquisition)	Germany, China	Small PV power station owner, less than 1MW	Grid company/	Grid company preferentially dispatches	Government pricing	Government pricing
Net electricity metering	California, etc.	(For household) small PV system owner	Utility company	Direct participation in electricity market	Owner power purchase price	

Figure 11-2 Comparison of electricity market and support policy mechanism [161]



Mechanisms and responsibilities for system balancing

There may be two property types of (medium- and long-term trading) contract types in bilateral market: financial contracts or physical contracts. Financial contracts often do not need to be physically delivered in the spot market but are marked against the spot market price. Physical contracts need to be physically delivered in the spot market and will be input into the clearing model in the spot market and considered as a whole. Physical contracts can compress the size of the spot market.

Spot markets plays an important role in connecting market trading and physical operation. From the operation practice of major foreign electricity markets, the trading size of the spot market can account for 30% to 80% of the total trading volume of the electricity market, mainly in the day-ahead market. The main role of the intraday market is to support market members to fine-tune their power generation and consumption plans. The real-time market ensures the real-time balance of the system, providing economic signals for congestion management and ancillary services for the system. The trading volume is typically relatively small, about 1-2% of total market volume. With access to more variable new energy, the intraday market can provide institutional support for new energy to participate in market competition.

In the spot market, all power sources participating in the spot market adhere to uniform rules. In the European market, wind power companies that participate in the bidding for the day-ahead and hourly spot markets need to provide output forecasts and take responsibility for deviations. The penalty mechanism for deviation varies. The loss of revenue from the Spanish wind power output deviation penalty will account for 10% of the total revenue of the wind power suppliers. Due to the inherent variability and uncertainty of renewable energy, the bidding output and actual output may deviate greatly when renewable energy participates in the spot market, which weakens the competitiveness of renewable energy. In recent years, some markets in the U.S. and Germany have introduced

5-minute and 15-minute intraday markets, which is conducive for new energy power generation to participate in the intraday trading in the electricity market.

However, under the U.S. PPA mechanism, renewable energy units transfer their balancing responsibility to the electricity marketers. Power marketers have more balancing resources, such as self-owned units and medium - and long-term contracts with other units, and hence greater ability to bear the risk of balancing. At the same time, as the electricity marketers bear the risk of balancing responsibility, the tariff agreed in PPA will also be slightly lower than the wholesale market price. In the long run, price and revenue in the wholesale electricity market have declined but provided relatively high returns to flexible units. Market mechanisms of wind energy trading in different countries are compared in the following table.[162]

Table 11-3: Comparison of market mechanisms of wind energy trading in different countries [163]

Imbalance settlement method	Area	Characteristics
Dual price system	North Europe	Power generation side deviation adopts a dual price system, including upward adjustment and downward adjustment of the price.
	MISO	Penalty when the wind power output deviation exceeds 8% for continuous 20 min or more within 1 h
	NYISO	Exemption from penalty in general
ISO commitment	PJM	Penalty for output deviation
	ERCOT	Exemption from penalty when the planned output deviation is within 50%
	CAISO	The penalty is based on the net deviation of wind power output in one month
Launch the intraday market	Nord Pool, Spanish electricity market	After the end of the day-ahead market, enter the intraday market and rebalance according to the latest forecast results

Some countries have studied strategies such as day-ahead market bidding, aimed at maximizing the expected returns of wind power providers, joint pricing of wind power and energy storage, and joint pricing of multiple wind farms. Some research results show that wind power has a good frequency modulation performance and the economy of participating in the frequency modulation market. Wind power can also be purchased from conventional power supplies through bilateral reserve markets to minimize balance losses.

To sum up the international experience, the key to the market mechanism that facilitates the electricity trading and consumption of renewable energy lies in: 1) Market prices can reflect marginal power generation cost, so that renewable energy with a low marginal cost can be dispatched with priority. 2) Optimal prices for ancillary services incentivise conventional units to balance renewable energy and promote renewable energy to improve its controllability and participate in the provision of ancillary services. 3) Establishing a market risk management mechanism can hedge the risk of financial losses due to market price fluctuations and balancing costs.

China's progress and prospects for electricity market reform

The goal of electricity markets is to create efficient market competition

China's power market reform effort has been underway for several years, and electricity retail tariffs, power generation schedules, and consumption plans are still generally set by the government. China lacks wholesale electricity trading, and retail competition remains a work in progress. Market trading between power generators and users is limited, and market-based pricing has not yet to be established. This situation has led traditional power generators to focus on building new capacity to meet load, in turn constraining the development and utilization of new and renewable energy. It has been widely recognized that, without comprehensively deepening the reform of the electricity market and establishing an effective modern electricity market system, it will be difficult to promote the transformation of the development of the power industry and the optimization of the power structure, and it will be difficult to continuously improve the proportion of renewable energy generation and distributed energy generation in the power supply.

Since 2015, a new round of power reform has entered the implementation stage, paying more attention to establishing a modern market system and forming a new driving force and institutional guarantee. The Opinions on Further Deepening the Power System Reform, or Document #9 confirms that the goal is to build the market structure and market system of effective competition, and to form a mechanism whereby the market determines the price of energy. [164] The subsequent Implementation Opinions on Promoting the Construction of the Power Market proposes that regions with suitable conditions will establish a market-based power and electricity balance mechanism dominated by medium- and long-term trading and supplemented by spot trading, and set up an electricity market that manages risk through medium- and long-term trading, enables price discovery in the spot market, and includes a variety of power trading modalities and functions.

The electricity market still requires top-level design and a clear implementation path

China's power system reform has shifted from top-level design to implementation, and the construction of the electricity market has been tried by provincial governments in accordance with administrative jurisdiction. However, reform efforts are still dominated by management system reform, the design of the electricity market system is still imperfect, the path for setting up electricity markets is still unclear, and there are differences in the choice of market model and the design of trading instruments.

China is still exploring how to set up competitive wholesale electricity markets. Direct trading with tariff reduction as the expected target is generally carried out. In 2017, the national market-oriented electricity consumption accounted for about 25% of the total electricity consumption. However, if China aims to optimize power supply structure and improve system efficiency, it must establish the corresponding spot market and balancing mechanism, otherwise progress will be difficult to sustain. Without the construction of wholesale electricity market, the new round of electricity market reform will be unsuccessful.

Currently, most regions in China are expected to build provincial-level wholesale electricity markets first, but the medium- and long-term target should be cross-provincial regional markets for bilateral trading. The central government should be directly responsible for the construction of the wholesale electricity markets, whereas the local governments are responsible for retail markets. Moreover, it is necessary to further clarify the specific market rules such as preconditions, implementation paths, access mechanisms, bidding cycles, clearing mechanisms, pricing methods, settlement mechanisms, deviation penalties and subsidies for various type of electricity, including renewable energy, to participate in market trading. In addition, it is necessary to establish an appropriate ancillary service market, achieve the close coordination of various mechanism elements in the medium- and long-term, day-ahead and real-time, and effectively motivate market participants.

The immediate task of medium- and long-term trading is to accelerate retail choice

Medium- and long-term trading in China are mainly reflected in direct trading between large users, but trading has recently expanded to include more electricity generators and power users. In accordance with the requirements of the Notice on Actively Promoting Electricity Market Trading and Further Improving Trading Mechanism, in addition to the eight electricity spot market pilot areas where reform path for electricity generation and consumption plans can be designed according to actual situation.[165] Most areas in the country shall gradually liberalize the electricity generation and consumption plan according to the type of power generation and user scale, expand the scope of market entity, and substantially increase the scale of market (direct) electricity trading.

At present, the provincial governments generally guide all types of electricity generation and consumption plans and large-user direct trading (medium- and long-term trading), strictly control outsourcing of electricity, and intervene in trading prices. The key is to reduce inappropriate administrative interventions by local governments and to liberalize electricity generation and consumption plans and user options. On one hand, at the provincial level, China will liberalize electricity generation and consumption plans and user options, the coal power units approved after implementation of Document #9 will no longer set fixed monthly and annual generation plans, and electricity generation plans (and base electricity) for existing coal power plants will also be gradually reduced and cancelled. On the other hand, inter-provincially, China must break barriers, this requires liberalising electricity generation and consumption plans and retail choice. Local authorities should eliminate any restrictions on the participation of market entities in cross-provincial and cross-district trading and inter-market trading and allow generators to be independently selected and connected to grid.

The standardized spot market and auxiliary service market are the key tasks

In the early days of direct electricity purchase by large users, the trading volume has been limited. It has little impact on the grid dispatch and operation and the trading organisation in the electricity market. It can be simply implemented by physical delivery. As the direct trading scale of large users continues to expand in China, physical delivery will create a series of problems, and power and electricity balance will be faced with challenges. The root cause is the contradiction between medium- and long-term bilateral trading and the non-market-oriented spot trading, which is manifested in aspects such as transaction connection, grid peak regulation, new energy consumption, power generation plan implementation, congestion management and real-time balance. It is necessary to establish a sound electricity market system combining medium- and long-term trading with spot trading as soon as possible, so that the spot market can play an important role in connecting (medium- and long-term) market trading and (short-term) physical operations and provide reference for market members to negotiate and determine bilateral trading prices.

The Notice on Piloting the Construction of Electricity Spot Market named eight provinces as pilots and requires them to start the pilot operation of electricity spot market by the end of 2018.[166] The policy aims to establish intraday time-of-use tariffs and set up spot markets and the congestion management mechanisms under security constraints on the basis of defining the optimisation target of the spot market; organise market entity to carry out day-ahead, intraday, and real-time electricity trading, realize the organic connection between dispatch operation and market trading, promote the safe operation of the electricity system and the effective operation of the market, and form the commodity price of electricity that reflects the characteristics of time and location. The spot market pilot program also considers supporting mechanisms, including preferential power generation and power purchase for renewable energy, which are compatible with spot trading.

China faces major challenges setting up spot markets from the bottom up. We suggest China emphasize greater top-down coordination of design, to strengthen market norms and principles with the goal of establishing a relatively well-functioning spot power market by 2020.

We suggest that the next step of China's electricity market-oriented reform should give priority to setting up a day-ahead market, gradually transition toward a real-time market, and organize the intraday market in due time. For the intraday market, priority should be given to market areas with high proportions of intermittent generation such as wind and PV, to provide incentives for clean energy to participate in market competition.

Partial power and full power spot markets depend on local conditions. At present, China's electricity trading is mainly based on planned allocations, and some large users directly trade. It is easier to transition from China’s existing practices by adopting partial spot power markets covering a portion of trading. For provinces with high proportion of new energy and less market power, the full power spot mode can be explored. State Grid Corporation of China has explored spot market trading of "surplus" new energy

We encourage enabling large users to sign financial contracts for direct purchase of electricity and conduct financial settlement of the deviation electricity (according to the spot market price), so that the direct purchase electricity contract is included in the unified clearing calculation of the spot market.

The scope of the spot market shall be expanded. At present, the electricity spot market construction pilot should be organized in principle according to the existing electricity dispatch control area (considering cross-province and cross-district transmission and receiving electricity), and areas with conditions can actively explore the combined dispatch control area. With reference to the trend and experience of the integration of the European and US electricity markets, in order to realize the evolution to the future national electricity market system, the core rules of each province's spot market need to be as uniform as possible at the beginning.

China proposes to establish an auxiliary service sharing mechanism involving power users, and to carry out auxiliary service trading such as back-up and frequency modulation in the spot market. It is necessary to change the so-called ancillary service market with peak regulation as the core, synchronously construct electricity spot market and ancillary service market, and promote the simultaneous optimization and joint clearing of the electricity market and ancillary services in the spot market.

Shifting from direct purchase of electricity by large users to wholesale market trading

This round of electricity reform allows eligible power generation companies to invest and organize electricity sellers to enter the market, engage in electricity sales, and build a competition pattern of multiple electricity sellers. China is currently promoting a new retail electricity market with direct purchase of electricity by large users. However, competition in retail electricity sales depends on competitive wholesale markets. Electricity sellers in the power pool mode only compete on the retail side, which is to compete for end users. The sellers in bilateral electricity trades must participate in both retail and wholesale competition. Therefore, the key is to link electricity retail and competitive wholesale markets, and thus requires reform of electricity retail and wholesale markets. In addition, it is necessary to guarantee retail choice. For example, all approved electricity transmission and distribution tariff categories can participate in electricity market trading with full power, businesses in industrial or office parks can be bundled and represented by electricity sellers to participate in electricity market trading, and local grids can participate in electricity market trading.

Recommendations for renewable energy market participation

Gradually promote renewable energy participation in competitive electricity trading

China has seen rapid growth in clean energy in recent years, but still faces solar, wind, and hydro curtailment along with a deficit in feed-in tariff subsidies. Lack of competition and trading mechanism in the electricity market play a central role in these problems. In the competitive electricity market, grid connection faces problems of technical standards and market access, and consumption faces obstacles of trading between market entities.

Clearing wholesale electricity markets according to the principle of minimum system cost requires a balance between supply and demand. Participation of renewable energy in wholesale markets is not about selling zero-cost electricity. Rather, renewable participation in wholesale markets can incentivize market entities to trade through the wholesale market, to operate renewable energy and other power sources more efficiently, to promote optimization of the electricity system, and to promote efficient development and utilization of additional renewable energy.

Wind and solar energy market trading does not depend on reaching grid parity with coal prices—parity is neither a precondition nor a sufficient condition. Wind and solar energy can participate in market trading before realizing grid parity. The so-called "parity online" does not mean relying solely on the electricity market. For example, large-scale new energy power stations in Germany, the U.K., and the U.S. participate in the competitive wholesale market. At the same time, policies in these countries reduce the risk faced by renewable energy sources and stabilize annual installations of new wind and solar via mechanisms such as market premiums, the CFD, and a quota system such as the Renewable Portfolio Standards in the U.S. That said, renewable generators cannot ignore market risk when planning projects. Electricity prices fluctuate with supply and demand and the prices of fuels for conventional generation, affecting renewable producers. In addition, there are prices of auxiliary services and network congestion. It is worth noting that a sustained decline in the clearing price in the spot market could lead to higher demand from various generators for subsidies and capacity support.

In the process of building the electricity market system, China has also actively promoted the participation of new energy in the medium- and long-term and spot market trading, but the specific mechanism and linkage mechanism are still unclear. The Notice on Actively Promoting Electricity Market Trading and Further Improving Trading Mechanism for promoting planned renewable energy sources, such as wind power and solar power generation, to participate in direct trading, trading in alternative thermal power generation rights and pilot spot trading across provinces and regions in addition to guaranteeing utilization time. The Notice on Piloting the Construction of Electricity Spot Market requires that the spot pilot program should fully consider the connection with the implementation mechanism for preferential power generation and power purchase system and supportive acquisition mechanism for renewable energy.[7]

China should promote the transformation of new energy enterprises into competitive electricity market entities in accordance with the construction of electricity market and the development process of new energy electricity. In addition to hydropower stations, large wind farms and solar power stations, distributed wind power and distributed generation investment enterprises (owners) are expected to become the market entities in the new energy sector. However, new energy microgrid owners are expected to be more innovative in terms of market modes and trading mechanisms. According to the regulations, the new energy microgrid operation entities, as electricity sellers (Type II electricity sellers) with the right to operate distribution grid, shall assume the electricity supply service (responsibility) within the microgrid and be responsible for electricity exchange between the micro-grid and the external grid. In addition, they shall sell electricity to internal and external users, establish a price system for both buyers and sellers to negotiate on their own, and even establish a trading system for various energy markets including cooling, heating and electricity. New energy microgrids also participates in ancillary service trading as an independent ancillary service provider.

Embedding priority dispatch of renewables in medium- and long-term trading rules

One of China's current tasks is to make the connection between preferential power generation and market-oriented consumption. Under the preferential power generation system, the preferential power generation and supportive acquisition system should be embedded into the medium- and long-term trading rules, and the preferential power purchase and preferential power generation shall be regarded as annual electricity trading contracts. The planned renewable energy preferential power generation contract (annual electricity trading contract) is transferable. (It is also necessary to encourage cross-provincial transfers of preferential power purchase contracts and promote cross-provincial and cross-district consumption of renewable energy.) In addition, the auction mechanism for renewable energy projects can also be regarded as a capacity purchase mechanism in the electricity market.

Participation of RE in market trading before 2020 with introduction of PPAs

The participation of renewable energy in medium- and long-term trading requires further liberalization of power generation and consumption plans and user options inside and outside the province. We shall guide and promote power users to conduct market-oriented trading with clean energy power generators such as hydropower, wind power and solar power generation, liberalize the power purchase right of grid companies, power users and electricity sellers inside and outside the province, and include renewable cross-provincial trading in transmission channel capacity. The trading price shall be decided by the parties through consultation or based on the market reference price. For example, Sichuan's Implementation Opinions on Deepening the Reform of Sichuan Electricity System requires that the centralized wind power and PV power generation in Sichuan grid participate in the electricity market in wet season, and the settlement shall be made according to the average price of off-grid power transmission in wet season.[167]

In many local electricity reform pilot programs, it is proposed to promote renewable energy consumption through alternative power generation mode. In the near future, it should also be encouraged to conduct the consumption of wind curtailment, PV curtailment and electricity limitation through medium- and long-term trading such as new energy generation right trading and replacement trading inside and outside the province. However, it must be emphasized that at present, the "generation right trading" and "alternative trading" of coal power enterprises transferring planned electricity to new energy enterprises in some regions of China are the products of coal power's access to planned electricity. The foundation should be lost with the gradual liberalization of power generation and consumption plans and the cancellation of coal power plans.

The grid has to serve trading. Allow new energy to supply electricity to users in a "special line" manner. Allow local grids to collaborate with the surrounding provincial grids. Encourage cross-provincial and cross-district net-to-net and net-to-point direct trading, orderly support point-to-net and point-to-point direct trading, and promote large-scale clean energy consumption. In the future, it is necessary to strengthen the formulation of implementation rules and strengthen supervision.

Participation of renewables in the spot and ancillary services markets after 2020

The spot market is the core of the modern electricity market. In the mature electricity market in Europe and the U.S., renewable energy not only benefits from the flexibility provided by the mature spot market, but also provides a vital way for new energy power generation to participate in the electricity market.

The construction of China's spot market has just started recently. It is expected that with the gradual maturity of the spot market operation around 2020, we can gradually explore the participation of renewable energy in the spot market, and preferential consumption can be achieved through a combination of market competition and government subsidies[168]. With reference to international experience, new energy enterprises can directly participate in the spot market, and the government can subsidize them through CFD and premium competition as needed. One is the CFD. New energy power generation enterprises participate in the bidding for new projects. After winning the bid, they sign a CFD with the government to obtain benchmark tariff. During the contract period, all the electricity sold by new energy enterprises is settled at this price. At the same time, new energy enterprises participate in the spot market trading, and the market returns refund for any overpayment or a supplemental payment for any deficiency. If the market price is lower than the benchmark tariff, the insufficient part is paid by the government or consumers; On the contrary, the new energy enterprises return excess returns. The other one is the market premium mode. New energy power generation and other units participate in market competition according to the same rules, and obtain subsidies according to a certain proportion on the basis of market price. The subsidy amount can be fixed value or adjusted according to fluctuation of tariff.

In the future, as technology matures and the cost of renewable energy declines, subsidies can be gradually reduced, making renewable energy market-oriented and eventually withdrawing from the fiscal subsidy policy.

Establish market-based trading and risk response mechanisms

In summary, combined with the construction of China's electricity medium- and long-term trading, spot market and financial futures market, renewable energy electricity can explore the following trading modes and risk response modes:

Model 1: Renewable energy power company signs a power purchase agreement with electricity seller. The two sides can agree on fixed electricity purchase price, as well as the compensation mechanism of wind and PV curtailment and time-of-use tariff, thereby mobilizing the power company to sell renewable energy in the wholesale market. If it is combined with renewable energy power quota system and green certificate trading, it will be more conducive to the implementation of this market-oriented trading mode.

Model 2: Renewable energy power company signs financial CFD (or integrated/virtual power purchase agreement) with power users and then participate in the wholesale electricity market bidding. The electricity will be sold to the electricity seller according to the actual market tariff, and the power user pays the difference between the actual market tariff and the agreed tariff for renewable electricity.

Model 3: Renewable energy power company directly participates in the wholesale electricity market bidding and purchases hedging products to mitigate risk.

Explore distributed power generation market on the electricity retail side

Distributed power generation represents a new direction and new form of energy development, but the monopolistic (transmission) distribution grid and the monopolistic user-side sales market are not suitable for the development needs and characteristics of large-scale distributed new energy.

Current analysis of the influence and growth of distributed power generation and energy storage on the future electricity market is insufficient, and requires breaking out the roles of microgrids, incremental distribution grids, and other elements. More distributed trading helps large power grids to solve power balance and price fluctuation risk, and even change the way the original market is built. More research and exploration are needed. For example, a DSO distributed power generation trading platform on the electricity retail side should be established.

11.2 Market Operation and Dispatch

Electricity scheduling and dispatch practices in China are heavily reliant on central administrative planning. Well-intended initiatives have fragmented the market along multiple dimensions. This section describes international electricity market operational principles and best practices, with the goal of dispelling some common misconceptions and related concerns about the power market in China and concludes with an explanation of how fundamental power market principles address all these concerns and help maintain an efficient, reliable, and affordable power system. And finally, the section presents potential lessons for market operation in China.

Before going into details, it is important to clarify a few key terms used in this chapter. Scheduling is a generic term used by planners, generation groups, and grid companies for short-term planning actions such as scheduling generating units for the next day or next week. Schedules can be made by the generation group, indicating a willingness to make its capacity available, or by the grid operator. A unit that has been scheduled may not necessarily be turned on in the operation hour. The grid operator performs security-constrained unit commitment and dispatch. Security-constrained unit commitment is the process of turning on (committing) resources to meet load while respecting generation and transmission system characteristics. Dispatch follows unit commitment and determines the level at which each committed resource should be operated. In advanced economies, unit commitment and dispatch follow the economic principle of minimizing operating cost, which will be described in more details later. While current grid-operation software typically solves unit commitment and economic dispatch together, they are two distinct mathematical problems. The unit commitment problem aims to identify the least-cost subset of generation units that would satisfy the expected load when many possible combinations of units could achieve the load requirement. Economic dispatch is based on the selected subset of generators already committed/connected to the system and solves for the optimum operating strategy for these units.

International Experience in Electricity Market Operations

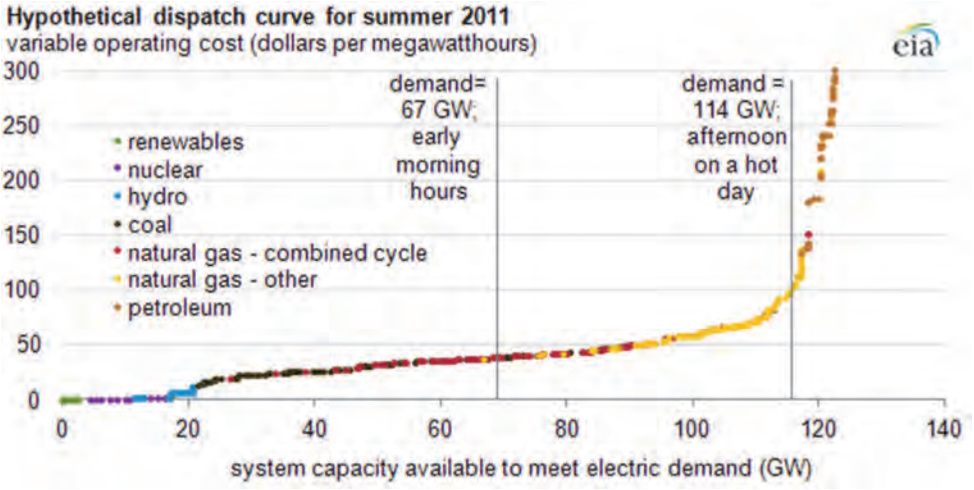
Unlike the brand-new design and establishment of the electricity market in China, the electricity markets in the United States and other advanced economies have decades of operation experience and have been making some incremental changes in recent years in the pursuit of a more reliable, efficient, and affordable system. This section will explain some fundamental electricity market operation principles as well as some recent updates with a focus on their application in China.

Power System Operation with Economic Dispatch

The operational core of organized electricity markets, and in many power systems without a market, is security-constrained unit commitment and economic dispatch. This means operating the generation facilities to "produce energy at the lowest cost to reliably serve consumers, recognizing any operational limits of generation and transmission facilities."[169]

Electric system operators commit and dispatch generation units in the order of lowest variable operating cost to highest variable operating cost to meet the expected electricity demand plus a reserve margin. As Figure 2 illustrates, wind and solar PV have a variable operating cost near zero and are at the bottom of a dispatch curve. Therefore, in an economic dispatch, they are almost always fully dispatched. Nuclear and hydro have low operating cost and are next in order. Coal and natural gas combined cycle (CC) units have higher operating costs, so they are dispatched after nuclear and hydro. In Figure 2, only units up to the natural gas combined cycle are dispatched at low demand periods, such as in the early morning hours, and the units on the right side of the demand line are not dispatched. In such case, the natural gas combined cycle unit on the margin is called the "marginal unit" which would set the energy price for that time period for the system. All units would be cleared at the same energy price. Natural gas combustion turbines and diesel generators have very high operating cost, and in this example, they are only dispatched when there is very high demand (such as in the afternoon on a hot summer day). They are referred to as "peaking units."

Figure 11-4 Hypothetical dispatch curve [170]



The system operator must also ensure sufficient transmission capability and system reliability. Transmission flows are monitored closely to ensure that they stay within voltage and reliability limits. Corrective actions such as curtailing schedules or changing dispatch, or even load shedding, must be taken if system reliability is out of bounds.

Power Market Principles

Four power market principles are important for the reliable and efficient operation of the power market, especially one with high penetration of renewable energy: 1) Principle one is consistency between the pricing mechanisms, and using prices to incentivize the resources to follow real-time dispatch; 2) Principle two is market neutrality and market operation based on cost and performance data of all resources, regardless of the type of technology or underlying bilateral contracts; 3) Principle three is unbundling prices to send accurate price signals for each service and avoid price averaging for different types of desired services; 4) Principle four is market coordination or expansion to facilitate renewable integration and lower operation costs.

Using prices to incentivize following dispatch

What is fundamental to the bid-based market design is that prices create incentives for the market participants to take actions that are consistent with reliable power system operation. This means prices reflect actual operating conditions, and the market pricing mechanisms between the day-ahead and real-time markets converge over time and reward following system instructions. The LMP mechanism and the market architecture in the United States are explained below, using simplified examples to illustrate how this setup creates the right price incentives for market participants.

In the organized markets in the United States, the locational marginal price (LMP) is used to price energy purchases and sales. The LMP could be expressed as the function below:

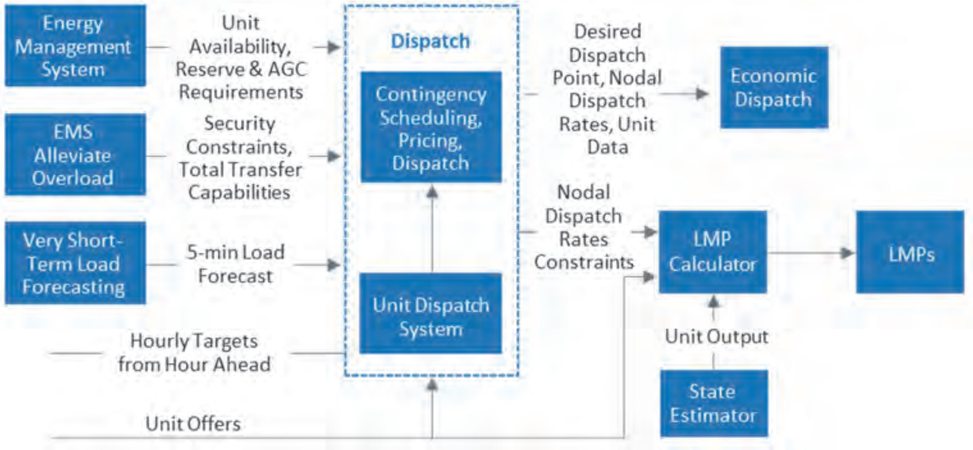
LMP = system energy price + transmission congestion cost + cost of marginal losses

All three components of the LMP are calculated in both day-ahead and real time. The system energy price represents the price of energy at optimal dispatch, ignoring congestion and losses. The energy price is the same for every bus in the system. For example, as shown in Figure 2, the price at the intersection of demand and supply is the energy price for that system. Congestion price is the price for binding constraints, calculated using the cost of the marginal unit for each binding constraint (also called the shadow price). This price will vary by location if the system is constrained. The load pays the congestion price, and the generation receives the congestion price. The loss price is calculated using a penalty factor, which is calculated at the bus and represents the price for the marginal system losses caused by the increment of power injection or withdrawal. It will vary by location. As with congestion price, the load pays the loss price and the generation receives the loss price. Because LMP is the sum of the three prices, the price the generation receives is rarely zero. Even if the system energy price can, at certain five-minute intervals, be zero or even negative, the average LMP is usually much higher—around $25–35 for PJM in 2017, as illustrated in Figure 6.

The U.S. organized markets use a two-settlement process: the day-ahead (DA) market and the real-time (RT)/ balancing market. Separate settlements are performed for each market. The DA market is financial.[171] Market participants purchase and sell energy at binding DA prices, and transmission customers can schedule bilateral transactions at binding DA congestion charges based on the differences in the LMP between the source and the sink of the transaction. All generation must participate in the DA market, while load participation in the DA market is optional. The DA market can also include virtual bids and price-sensitive demand. Prices are calculated hourly in the DA market. The DA market clearing process incorporates reliability requirements and reserve obligations in the analysis and respects the physical operation limitations of the generators.

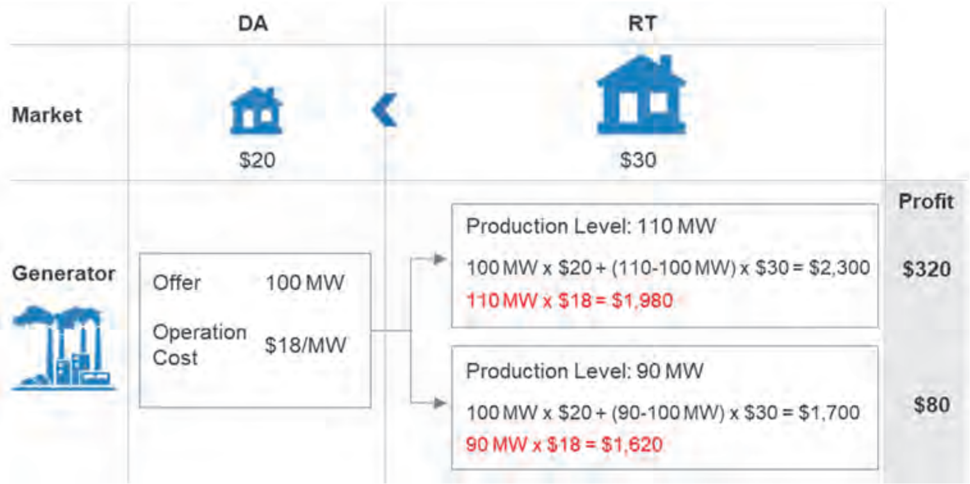
The RT market is a physical market based on actual system operation conditions with data from the energy management system (EMS). The RT LMPs are calculated every 5 minutes using unit output data from the state estimator and other system constraints information from the EMS. Figure 3 shows a diagram of the RT dispatch process in a U.S. power market. The settlement is based on deviations from the DA positions using RT LMPs.

Figure 11-5 Real-time dispatch in U.S. power market [172]



The LMP incentivizes market participants to take actions that are consistent with reliable power system operation. The following examples demonstrate how this works. Penalties for violating power balance constraint and transmission constraint are not included in the examples. In actual operation, there is a power balance penalty for under- and over-generation that scales up with the violation quantity, as well as voltage and N-1 constraint violation penalties, all of which are designed to ensure that generators follow the dispatch signal.

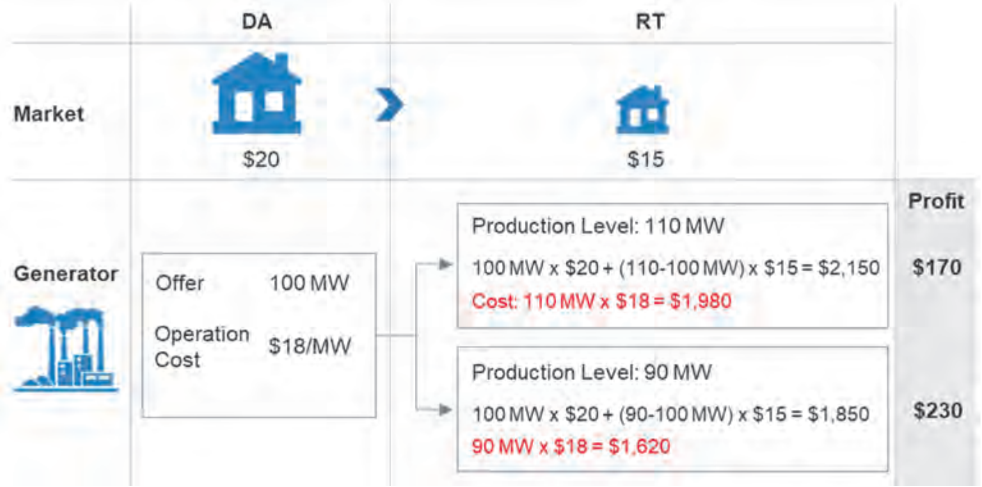
Figure 11-6 Example 1 of generator profit when RT demand is higher than DA demand



In the first example, as illustrated in Figure 4, the RT demand is greater than DA demand. In this case, the RT LMP ($30) is higher than the DA LMP ($20). The system needs the generators to dispatch up. If a generator with a variable operation cost of $18 offered 100 MW in the DA market, and the DA market cleared at $20, the generator would lock in the $20 price for the 100 MW it offered. In the RT market, if the generator produces 110 MW, it would receive a total of $2,300 in revenue, minus the operation cost of $1,980, netting $320 in profit. But if the generator only produces 90 MW in RT, it would receive a total of $1,700 in revenue, minus $1,620 operation cost, netting $80 in profit. The LMP used in DA and RT provides the generator with the economic incentive to dispatch up according to system needs.

What if the opposite happens?

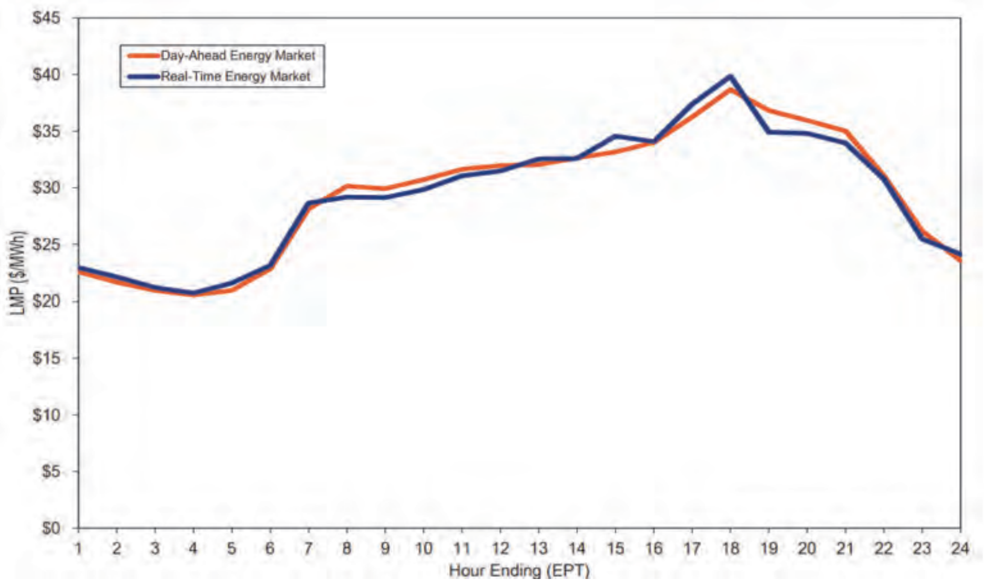
Figure 11-7 Example 2 of generator profit when RT demand is lower than DA demand



In the second example, the RT demand is lower than the DA demand, resulting in a lower RT LMP of US$ 15. The system needs the generators to dispatch down. Suppose the same generator made the same offer in DA. In RT operation, if the generator produces 110 MW, it would receive US$ 2,150 in revenue. But because its operation cost is US$ 1,980, it nets a profit of US$ 170. If it produces 90 MW in RT, then it would receive a total of US$ 1,850 in revenue, minus US$ 1,620 in operation cost, netting a profit of $230. In this case, the generator benefits economically from dispatching down based on system needs.

These examples illustrate how the LMP mechanism used in the DA and RT markets in the United States incentivizes the resources to follow actions that are consistent with reliable system operation. This, along with the flexibility provided by the virtual bidding rules, drives the price convergence between the DA and RT market prices, which in turn offers predictability and consistency for market participants and investors.[173] As shown in Figure 6, the average LMP prices in the DA and RT markets are usually very closely related.

Figure 11-8 Average hourly LMP price (US$/MWh) in PJM DA and RT markets in 2017 [174]



Resource-neutrality principle

Resource neutrality is an important principle of the U.S. electricity market.[175] One, this means the market is technology neutral. The resources are dispatched based on their cost and performance, subject to system constraints. As long as the resource meets the system requirements (such as start-up time, ramp rate, capacity, duration of service), the market is neutral as to what the underlying technology is. This offers a level playing field for all technologies and allows new technologies or innovations to participate in the market. Two, the organized U.S. electricity markets perform market-wide dispatch, which means the same set of market rules apply to all resources in the market regardless of underlying power purchase agreements.

First, it is important that all technologies are treated equally, as opposed to having one set of market rules for renewable generation and another for conventional generation. Experience in the U.S. electricity market demonstrates that without creating a separate electricity market for renewables, renewable and conventional generators can use the neutral market rules to achieve their objectives economically.

In the second example discussed in the previous section, if the generator is a wind or solar PV plant, it would have close to zero operation cost. In this case, when the RT price drops, the plants with high operation cost (such as coal plants or natural gas combustion turbine plants) are incentivized to dispatch down while the renewable plant can still produce its full output while maintaining a profit. Therefore, China's renewable guaranteed purchase rule would be achieved automatically under such an electricity market design. Renewable generation will keep producing at its full output until it is no longer economic to do so, such as when the LMP goes down to zero (or negative if there is a production tax credit available for the renewable generator). At such times, the curtailment of the renewable plant would be economic.

As for conventional generators such as coal, nuclear, and CHP plants, there is a common misconception in China that special rules are necessary to accommodate their minimum generation levels. However, these generators can adapt to existing electricity market rules. A common practice for generators with a minimum generation level is to bid the minimum generation quantity at the lowest price possible to be dispatched at least above that level.

Figure 11-9 Offer curves of six selected generators in ERCOT at noon on March 23, 2017

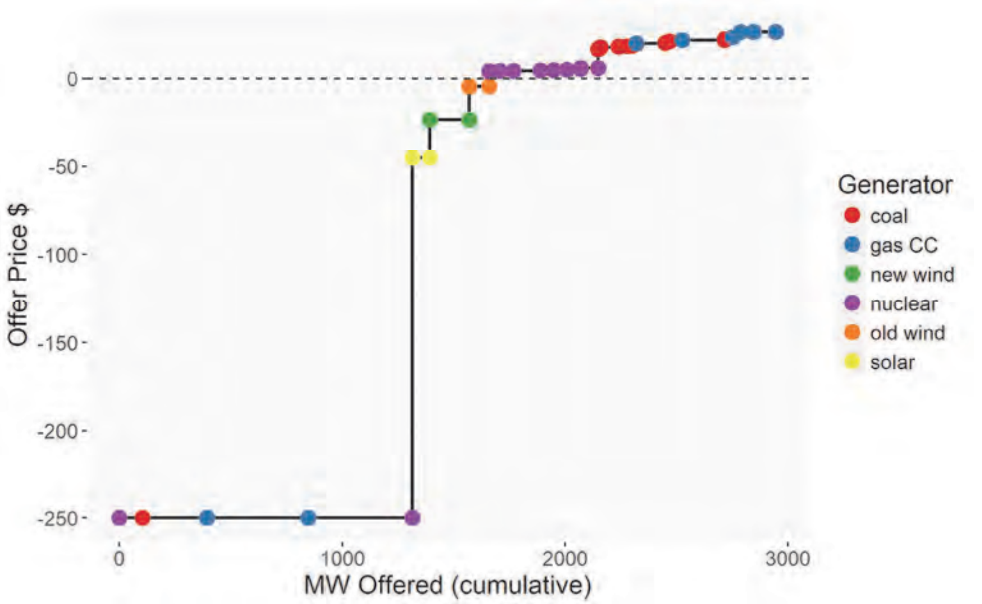


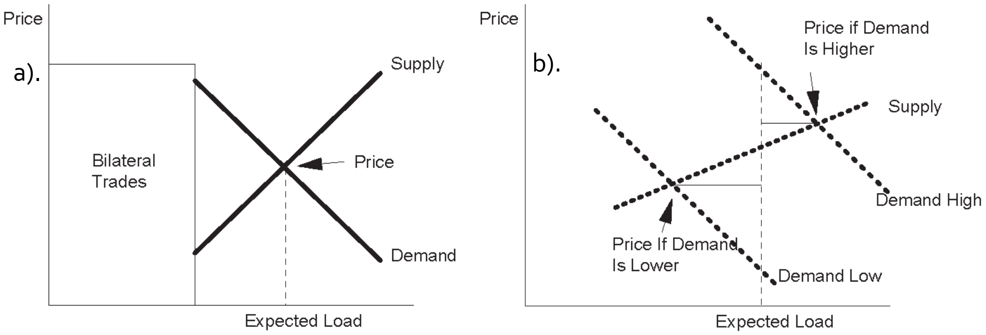
Figure 11-9 shows the real offers from six selected generators in the U.S. ERCOT market at noon on March 23, 2017. As the graph illustrates, the nuclear, coal, and gas combined cycle (CC) plants all bid a considerable quantity of the plants at or around the floor price of -$250, which is the lowest allowable bid in ERCOT. Their remaining capacities were offered at their operation cost curve: nuclear (around $5), followed by coal (around $20) and natural gas (from around $20 to $26). This bid strategy ensures that they would at least be dispatched at their minimum generation level. When the DA market clears, all their accepted capacity would receive the DA LMP price. If the RT market price increases, because they have guaranteed at least a minimum-generation level online, they would be able to dispatch up. If they did not use this strategy and instead bid their entire capacity at their average operation cost, the market could clear at only 10% of their generation level or even lower, making it very costly for them to run.

The solar plant in this example, because it had a production tax credit and expected high output at noon, was bidding at around -$45.[176] The new wind plant, which still had a production tax credit, bid at around -$23, and the old wind plant, with its production tax credit expiring, bid a little higher than the new wind plant at -$4. This graph also serves to dispel another common misconception in China that only the renewables bid below zero. Real bid data show that it is common for conventional generators to bid their minimum generation levels at much lower prices than renewables to ensure dispatch.

Second, in market-wide dispatch, all resources abide by the same set of rules regardless of underlying power purchase agreements. Freely negotiated bilateral contracts between generators and load can bring many benefits, including allowing sellers and buyers to manage their price risks, increasing market competitiveness, and reducing market power.[177] Bilateral contracts are an important part of a power market. For instance in PJM, 77.5% of day-ahead demand and 73.3% of real-time demand is served by bilateral contracts; in NYISO, 40% of the day-ahead demand is met by bilateral contracts.[178] Market-wide economic dispatch is achieved when all trades are ultimately fed into the centrally organized scheduling and dispatch system and be treated the same as all the other resources.[179]

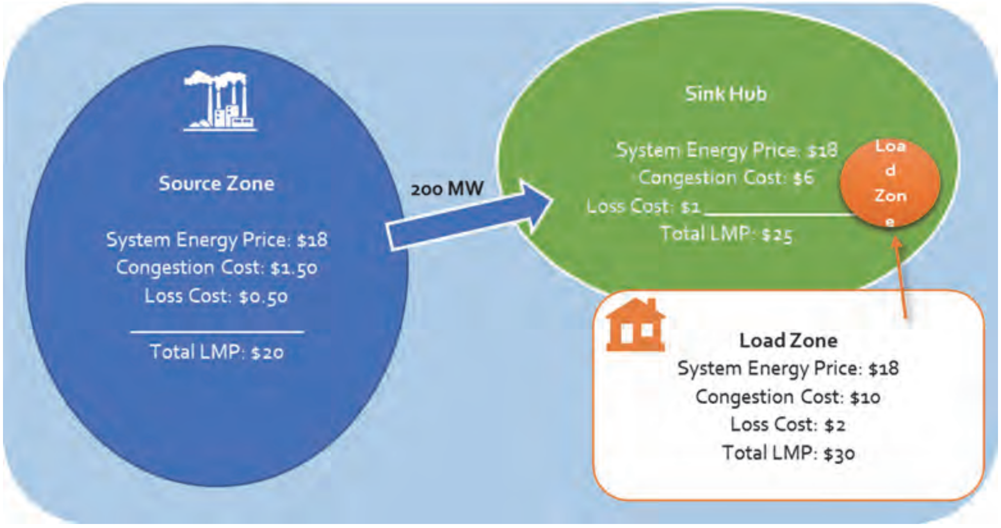
If the bilateral contracts do not participate in the centralized scheduling and dispatch, it essentially creates an energy and price block separate from the market, therefore distorting the market price, as illustrated in Figure 8a. Only when all resources, including those with bilateral contracts, participate in the centralized scheduling and dispatch, can the supply and demand converge on the right market price.

Figure 11-10 Supply and demand curve if bilateral trades do not participate in centralized dispatch; 8b. Supply and demand curve if all resources are centrally dispatched[180]



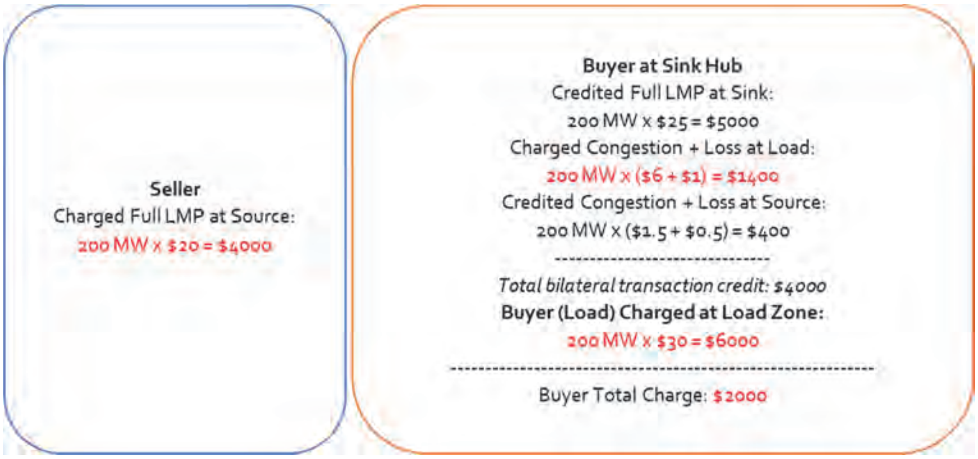
In the U.S. electricity markets, bilateral power purchase contracts do not change the dispatch; they only affect settlement.[181] Bilateral contracts are settled using the LMP price at the contract-specified injection and withdrawal nodes, and the title to the energy specified in the bilateral contract is passed to the buyer at the source specified. This mechanism is illustrated in Figure 9 below. A generator (the seller) in the source zone has a bilateral contract of 200 MW with a load (the buyer) in the load zone for 200 MW. The injection is at the source zone, and the withdrawal is at the sink hub.

Figure 11-11 Illustration of a bilateral contract from the electricity market perspective



The settlement of the bilateral contract in the market would be as below. The financial settlements between the buyer and the seller and between the buyer and the final customers are all external to the regional transmission organization (RTO). The economics of the bilateral contract depend on the specific terms of those contracts.

Figure 11-12 Settlement of the bilateral contract from the electricity market perspective; transactions outside of the market are not included



Seller
Charged Full LMP at Source:
200 MW x $20 = $4000

Buyer at Sink Hub
Credited Full LMP at Sink:
200 MW x $25 = $5000
Charged Congestion + Loss at Load:
200 MW x ($6 + $1) = $1400
Credited Congestion + Loss at Source:
200 MW x ($1.5 + $0.5) = $400

Total bilateral transaction credit: $4000
Buyer (Load) Charged at Load Zone:
200 MW x $30 = $6000

Buyer Total Charge: $2000

The example above shows that a bilateral contract between a generator and a load only affects settlement but does not affect the physical dispatch of the plant. The resource neutral principle ensures that all resources are dispatched according to the same set of rules. Generators with power purchase agreements are not separated from the normal dispatch process.

Similarly, a financial transmission right also affects settlement, but not the actual dispatch. Financial transmission right in the U.S. power market is a financial contract that entitles the holder to the revenue (or charges) based on the LMP differences across a given path.[182] It is a financially binding entitlement (or obligation), not a physical right to transmission, and is independent of energy delivery.[183] It is used to protect firm transmission customers from potential congestion costs and facilitates the forward energy market by providing a mechanism to manage LMP risk due to transmission congestion.

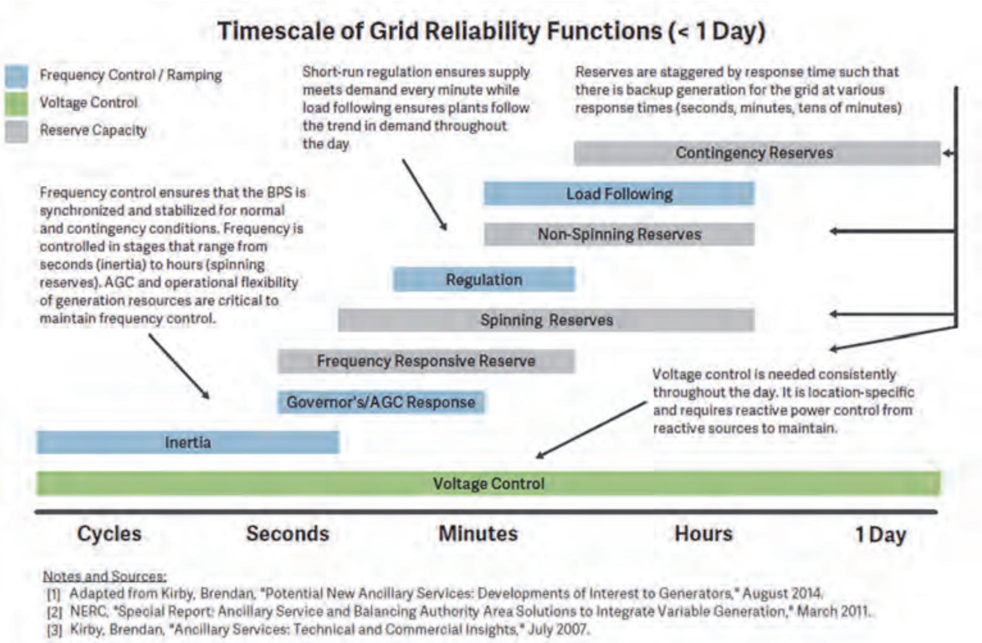
Unbundling services to provide accurate price signals

The third best practice of electricity market design is to unbundle the system services to provide accurate price signals. In China, broad categories of ancillary services are lumped together, including automatic generation control (AGC), black start, peak regulation, etc. Traditionally, all centrally dispatched coal plants are required to provide these services. This practice muffles the actual supply and demand for each of the different services and is not conducive to market competition. The National Energy Administration in November 2017 released a work plan to improve the compensation for ancillary services in China, requiring all generators to equally bear the cost of ancillary service provision and ordering the use of competitive mechanisms to determine the ancillary service provider.[184]

Experience from international electricity markets shows that unbundling different system services is important for enhancing reliability and market performance. As shown in Figure 11-13, a variety of grid reliability functions are needed for system operation and they have very different timescales, from milliseconds to hours. In the U.S. electricity market, different ancillary service products are created based on system needs (Figure 12). Survey of U.S. Ancillary Services Markets is a detailed survey of the ancillary service products in the U.S. electricity markets and their specific requirements.[185]

In general, three types of ancillary service products are optimized in the market: regulation, spinning, and non-spinning reserves. Regulation reserves (also called secondary frequency response) are procured to maintain system balance over short time frames, typically on the order of one to several seconds. Resources typically provide regulation reserve by adjusting their generation or load level according to the AGC signal from the system operator. Spinning and non-spinning reserve provide additional generation capacity in the event of a load increase or supply side output reduction. Spinning reserve is provided by online resources that are actively generating and have the ability to increase or decrease their output. Non-spinning reserve is provided by sources that are not actively generating but can start up and provide the needed service in a specific time frame, as required by the system operator. In general, regulation service has the highest market prices, followed by spinning reserves, and then non-spinning reserves.

Figure 11-13 Timescale of grid reliability functions [186]



Short-run regulation ensures supply meets demand every minute while load following ensures plants follow the trend in demand throughout the day

Reserves are staggered by response time such that there is backup generation for the grid at various response times (seconds, minutes, tens of minutes)

Frequency control ensures that the BPS is synchronized and stabilized for normal and contingency conditions. Frequency is controlled in stages that range from seconds (inertia) to hours (spinning reserves). AGC and operational flexibility of generation resources are critical to maintain frequency control.

Voltage control is needed consistently throughout the day. It is location-specific and requires reactive power control from reactive sources to maintain.

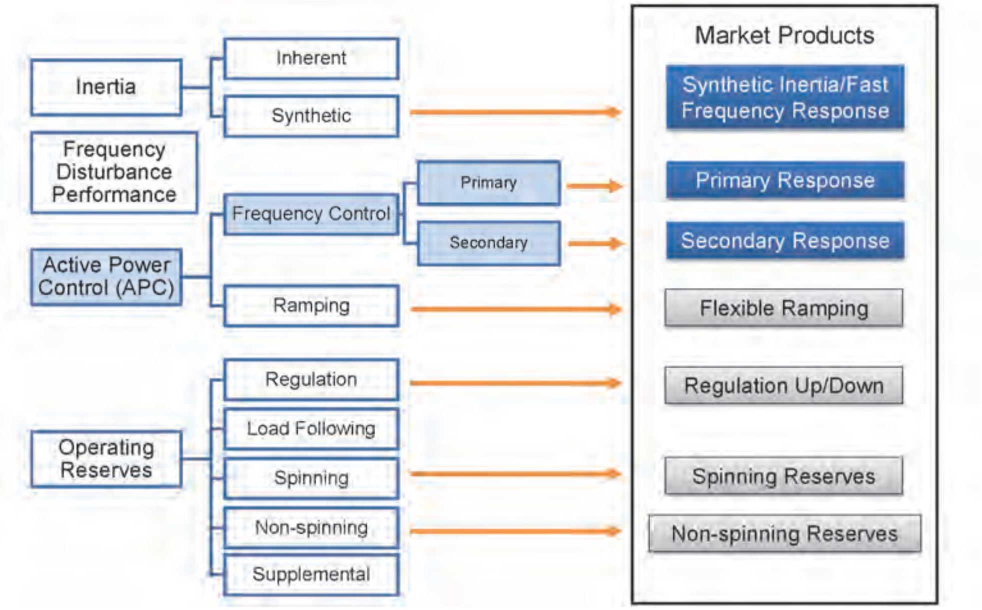
Notes and Sources:

[1] Adapted from Kirby, Brendan, "Potential New Ancillary Services: Developments of Interest to Generators," August 2014.

[2] NERC, "Special Report: Ancillary Service and Balancing Authority Area Solutions to Integrate Variable Generation," March 2011.

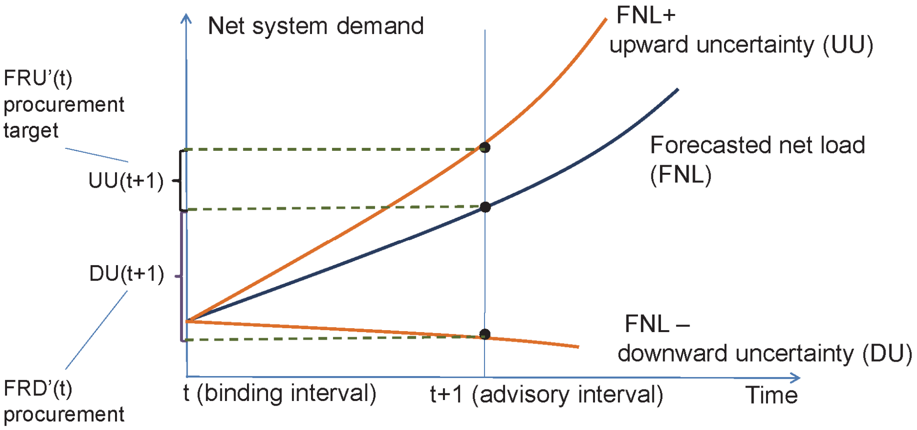
[3] Kirby, Brendan, "Ancillary Services: Technical and Commercial Insights," July 2007.

Figure 11-14 System reliability needs and corresponding market products in CAISO (white indicates existing products; blue indicates potential products) [187]



To address new challenges in system operation, new product or market mechanism is proposed and can be implemented if it is approved through a rigorous process of stakeholder involvement and modelling efforts. One distinctive need that can arise as more wind and solar capacity is added to the system is ramping. This is most prominent in California and illustrated in the famous duck curve, where the steep evening ramp is shown as the neck of the duck. High penetration of renewable energy increases flexible needs due to forecast changes and uncertainty. As a result, since November 2016, CAISO has implemented a new market for procuring real-time flexible ramping capacity (both upward and downward) to manage volatility and uncertainty of the real-time imbalance demand.[188] The difference between flexible ramping product and regulation reserve is that flexible ramping product addresses ramping issue before the binding real-time dispatch whereas regulation addresses the ramping issue after the binding real-time dispatch. Figure 11-14 shows the design of the flexible ramping product in CAISO.

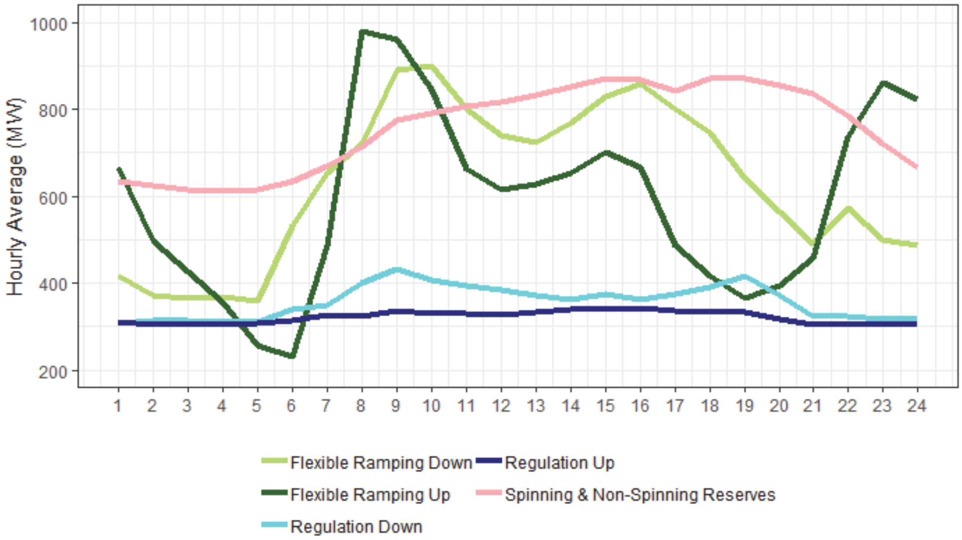
Figure 11-15 Design of flexible ramp-up and -down products[189]



FRU' and FRD' cover the uncertainty around the forecasted net load at t+1 (the advisory interval)

Flexible ramp up (FRU) is procured to meet the delta between current forecasted net load and the forecasted net load for the next time interval (5- or 15-minute) plus an upward uncertainty requirement. Reversely, flexible ramp down (FRD) is procured for the delta between current forecasted net load and the forecasted net load for the next time interval minus a downward uncertainty requirement. The net load equals to the total load minus wind and solar generation. The flex up uncertainty requirement is the 97.5 percentile, and the flex down uncertainty requirement is the 2.5 percentile.

Figure 11-16 Average daily ancillary service requirement and flexible ramping requirements in the RT market[190]



As Figure 11-16 shows, the demand for the flexible ramping product is very different from the demand for ancillary service product. Bundling the different services with an average price would eliminate the rising demand for flexible ramping in the morning and evening periods. Having a separate product for a specific system need helps send out distinct price signals that incentivize the provision of the product.

Regional Coordination

Coordination over a larger geographic and electrical footprint improves the cost-effectiveness of power system operations. China is a vast country with great geographic diversity both in renewable resources and in load. A larger balancing region leverages the smoothing effect of such diversity in supply and demand.[191] As described in Section 2.4., the de facto balancing area in China is at the provincial level, and adjustments of the intertie schedules are infrequent. If the balancing is carried out at the regional level, or even the national level, great system-wide production cost savings could be achieved. A recent study of the India system with 60 GW of wind and 100 GW of solar in 2022 shows that changing from state-level dispatch to regionally coordinated dispatch could result in 2.8% savings in total system operation cost annually, and a national dispatch could result in 3.5% savings in total system operation cost.[192]

Expanding regional coordination is also a trend in the United States. Since 2014, CAISO has launched a western Energy Imbalance Market (EIM) to conduct real-time trading of the differences between day-ahead forecast of electricity and the actual amount of electricity needed to meet the demand, i.e. the imbalance. The EIM footprint now includes portions of Arizona, California, Idaho, Nevada, Oregon, Utah, Washington, and Wyoming. Entry of a number of additional participants, including the Balancing Authority of Northern

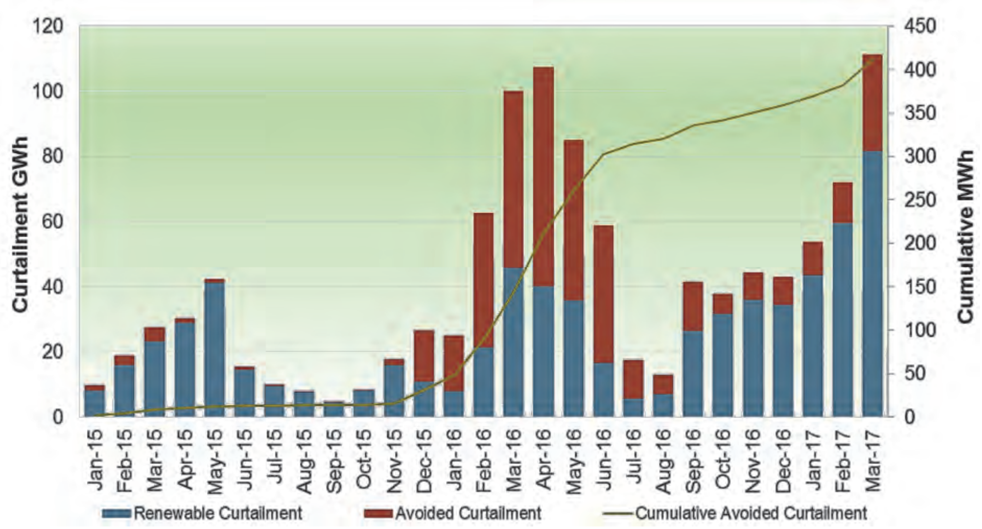
California/SMUD, Los Angeles Department of Power & Water, Seattle City Light, and Salt River Project is pending.[193] The EIM brings three streams of benefits: [194]

- More efficient dispatch, both inter- and intraregional, in the 15-minute market and real-time dispatch
- Reduced renewable energy curtailment
- Reduced flexibility ramping reserves needed in all balancing authority areas.

Such benefits are achieved because the EIM quickly dispatches resources to meet load across a broad geographic region. The EIM takes advantage of the reduction in wind and solar generation variability and the resulting generation-load imbalance that is inherent in having a larger geographic footprint. The geographic expansion also allows it to find the least-cost generation resources to contribute to the economic balancing of generation and load over a larger region, thus resulting in a lower price. In addition, the economic dispatch of EIM operates every 5 minutes, resulting in a more economic balancing than if regulating resources were used for all imbalances inside an hour.[195] As a result, the gross total benefit of the EIM, through the three streams of benefits described above, has reached $401.73 million from its inception in 2014 to June 2018.

In particular, reduction in renewable curtailment is an important benefit because California has ambitious renewable goals, but curtailment of renewable energy will also increase operation costs and carbon emissions. CAISO is projected to add an additional 4 GW of grid-connected renewables by 2020 and another 10 to 15 GW by 2030, bringing the total renewables to 38 GW.[196] During times of oversupply, CAISO first competitively selects the lowest-cost resources. Renewables can bid into the market in a way that reduces production when prices fall. This is considered "economic curtailment." Second, "self-scheduled cuts" are triggered to reduce generation from self-scheduled bids and prioritized using operational and tariff considerations. Third, if the two market-based measures still have not cleared the surplus of electricity, the last resort is for the ISO to manually intervene and call on specific renewable plants to reduce output. This exceptional dispatch only happens when grid reliability is at risk. The EIM has helped reduce curtailment (shown in Figure 14) and therefore avoid an equivalent of 305,112 tons of CO_2 emissions.

Figure 11-17 Avoided renewable curtailment as a result of EIM [37]



Potential Lessons for China

Electricity scheduling and dispatch practices in China are indicative of a system heavily reliant on central administrative planning, even as good-natured initiatives have fragmented the market along multiple dimensions.

International experience in electricity markets offers some potential lessons for the development of China's power market today. Security-constrained unit commitment and economic dispatch are at the core of electricity market design and have proven effective in lowering costs and improving efficiency in power system operation. Over time market rules can evolve to accommodate new challenges while adhering to four principles:

Prices are designed to encourage resources to follow dispatch signals. Shifting from a fixed tariff structure to a power market with prices set by supply and demand can already unleash a lot of the resource flexibility potential that previously was not incentivized. The pricing mechanisms in the DA and RT markets are designed to encourage rational behaviour from the resources and support subsequent actions that are consistent with the reliable operation of the power system. Such a setup can drive price convergence between the DA and RT markets, providing greater predictability for investors.

The market is neutral to the underlying technology and bilateral power purchasing contracts. This principle ensures fairness and efficiency of the power market, making it less prone to market power. The market is most efficient when it can choose the lowest-cost resource to meet its need under the reliability constraints. Whenever an administrative rule or a bilateral power purchasing contract influences such selection, it creates an out-of-merit dispatch. Such cases may be necessary for contingency purposes, but in general, the market is resource neutral.

Unbundling different system-required services can provide accurate price signals and incentivize system-desired behaviours from the market participants. The reliable operation of the power system requires many services of different duration, depth, response speed, and other characteristics. China traditionally has bundled all these services as a requirement. Power sector reform provides an opportunity to re-examine this practice and separate out the services needed. Experience in international power markets shows that distinguishing unique service needs helps send out accurate price signals and incentivize the required behaviour.

Regional expansion and coordination of electrical balancing areas have huge benefits including more efficient operation, reduced renewable curtailment, and reduced ramping reserve needs. China is a country with vast geographic coverage and diversity. Utilizing natural geographic smoothing of renewable variability and generation and load diversity through larger balancing areas or increased market footprint can help China achieve tremendous operational efficiency and cost savings.

11.3 Policy and market coordination

Energy systems rely on large amounts of regulation. Within the transition of energy systems, the design of individual policies is crucial to fulfil politically set targets and incentivize change. However, newly set policies or changed mechanisms often have unintended side effects on other policies, parts of the system or basic principles of the market design. This section sheds light on three examples in China in which the interaction of policies with other elements of the system is important to anticipate.

Alignment of renewable obligation and feed-in tariffs to avoid redundancy

As there are various mechanisms to support the expansion of renewable energies, a careful set-up of supporting policies is crucial. Within the context of policy redundancy, this section focuses on the mechanism Tsao et al. (2011) documented: in systems with parallel policies, the tightening of one measure will weaken the other in their function of meeting intended policy targets. Their findings suggest that the co-existence of renewable portfolio standards and carbon market policies lead to such an observation.

Similar to this, China relies on two different but interlinking renewable support policies: renewable obligation and a feed-in tariffs. Both policies fulfil similar purposes - the support of renewable energies – and both showed difficulties in their implementation in the past year.

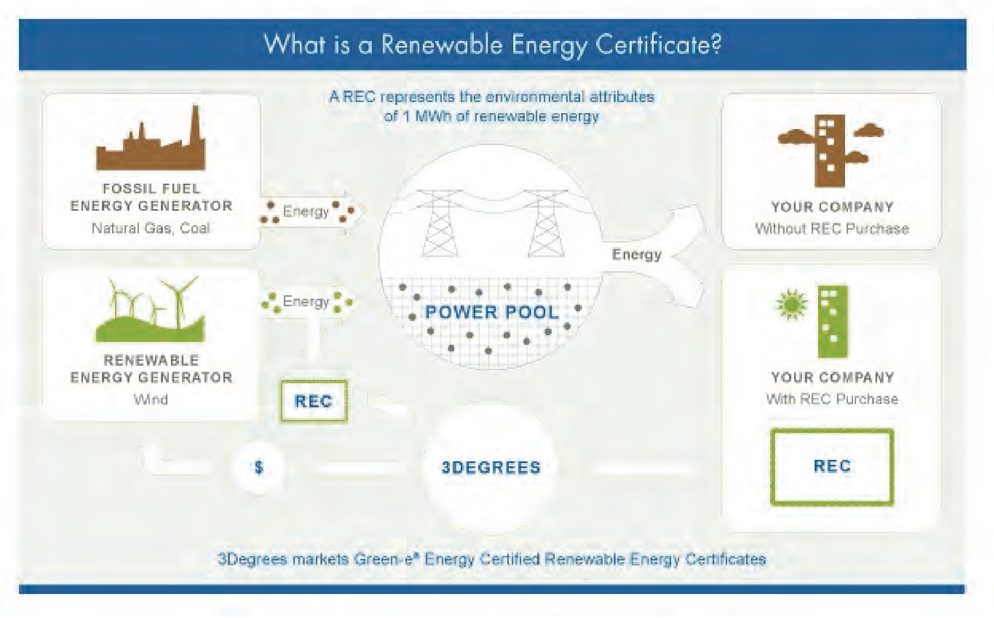
In May 2018, the Chinese government abruptly cut the subsidies for solar PV, resulting in 20GW less installed capacity than previously envisaged. Previously it was debated whether feed-in tariffs could be paid much longer due to uncertain income streams.

Additionally, the government issued a guideline that requires auction-based pricing for post-2018 utility-level wind and solar projects.[197] Even though details on how the policy will be implemented are not public yet, the role provincial governments will become more important, being organizers of the upcoming auction. Additionally, renewable obligation accounting is done on the basis of provincial boundaries. It is therefore important to carefully design both policies with regard to their interactions and control for the beneficial and detrimental effects regularly. Going further, the interaction between these policy instruments and the ongoing power market development is crucial as well and also needs to be considered.

Renewable obligation policy and its interaction with economic dispatch and the power market

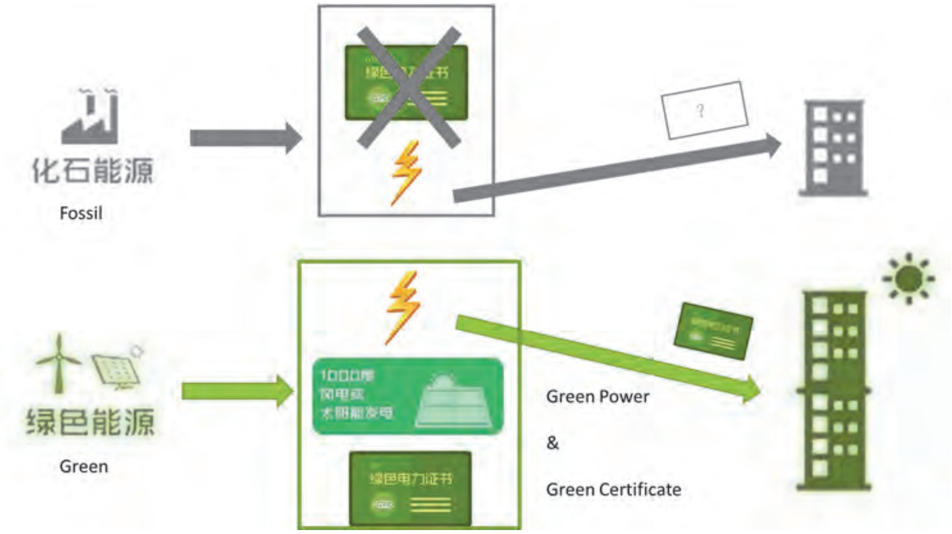
Conventionally, the renewable certificate is a label to represent the generation and use of renewable energy. It is tradable in a common market and would have positive monetized value within the constraint of the Renewable Portfolio System (RPS), i.e. the quota system requiring a minimum share of renewable in the power mix.

Figure 11-18. The generation of REC in typical US RPS system [198]



Such a renewable certificate market should therefore be an independent market in parallel with the power system (Figure 1). In China, the green power and the green certificate markets are largely bundled, at least as the current design. This leads to a fragmentation of the power market into one market for renewable electricity via the renewable certificates and one for conventional electricity. However, this set-up violates the economic efficiency principle of system operation, as it prevents equal access to the power market.

Figure 11-19. The generation of REC in China, bundling with green power flow [199]



The current mechanism of renewable obligations was set up to reduce curtailment rates. However, this approach neglects the function of a power market based on economic principles which grant renewables priority due to their near-zero marginal costs. Coupling renewable certificates to green power brings unnecessary complexity into a transitioning system. A more tailored design of renewable obligations that accounts for the economic principles of the power market and allows renewables to compete on a level playing ground can help to reduce curtailment and support renewable energies.

Decentralized solar PV trading and its implication

China issued the Decentralized, Market-based Renewable Trading policy in October 2017.[200] It regulates small-scale wind and solar PV projects (20 MW, connecting to 35kV or below; less than 50 MW, connecting to 110kV or below), from which the produced electricity is directly sold to and consumed by the nearby consumers. Within this arrangement, only partial distribution costs are added to the final consumption price. Details of this mechanism is not yet determined, mainly due to two factors: 1. Wholesale market and grid operation are functioning as one, hence revenues for the grid proportionality and solely depend on the electricity sold via the grid; 2. The producers and consumers are not responsible for balancing the market.

Dealing with these two factors implies interactions with other parts of the system: bypassing the grid and therefore diminishing distribution cost for consumers will reduce revenue streams for the incumbent power grid companies. This could structurally change the economics of the power system and should therefore be anticipated and accounted for. Secondly, a set-up in which electricity is produced and consumed decentralized brings new challenges such as balancing within small-grid solutions. Wind and solar PV requires flexible power systems that can cater these characteristics, hence a mechanism that can guarantee upward and downward system stability is needed.

In China, as mentioned last year in CNREC (2017), the independent T&D cost accounting was already finished over the country. And the tariff for grid is kWh-based largely for all consumers. Now, the transmission cost can be avoided in China case if the trading is deemed only occurred in the layer of "distribution grid" (He, 2018). The decentralized trading would fundamentally challenge the current revenue mode of the grid company in China.

Main finding and policy recommendations

The interaction of policies within the energy system is important to acknowledge as policies may have unwanted implications within other mechanisms. A carefully designed set of mechanisms can nurture development and help to fulfil policy targets. In the current system, some policies create redundancy, may hinder market-based development and could lead to market interruptions. Controlling interactions of policies is therefore an elementary building block.

12 Interconnectors in large power system with high shares of renewable energy

12.1 Summary

Improving the operation of China's transmission grid is essential to improving renewable integration and enabling a long-term transition to a high penetration of variable wind and solar energy. This chapter reviews China's progress in this field, discusses cases of international grid development aimed at enabling renewable transitions, and gives suggestions for potential improvements in China's grid planning and operations.

China's grid has expanded rapidly in recent decades to meet demand growth and enable renewable integration. China's most abundant energy supplies and highest electricity loads are located in geographically distant regions. By the end of 2017 China had basically completed the construction of grid connections between six main electricity regions. However, China's power grid development has been focused on large-capacity and long-distance UHV transmission, and many existing 500-kV and 750-kV inter-provincial and inter-regional transmission lines have seen low utilization. China's system also focuses on single-direction transfers of electricity from sending regions to high demand regions, making the system less flexible that it could be. Meanwhile, barriers to trading power between provinces remain high.

The chapter reviews recent grid planning experiences in Europe, which is characterized by large supplies of power from North Europe to countries in the South. The European Network of Transmission System Operators-Electricity (ENTSO-E) and individual TSOs are working together to optimize cross-zonal connections under the principle that bottlenecks and constraints should be resolved through investment wherever net positive socio-economic benefits (including lower environmental costs) can be achieved. European analysis of future grid development concludes that the continent will evolve into a highly meshed AC grid with point-to-point connections to a few countries in the North and South, plus highly-flexible DC interconnectors between regions.

With the European case in mind, the chapter analyses the flexible use of interconnectors in China, building upon the analysis in CREO 2017. The analysis shows that increases in grid flexible operation in China leads to substantially lower-cost electricity, due in part to lower needs for investment in thermal power plants or energy storage. The flexible grid scenario also shows reductions in CO_2 emissions, higher renewable energy penetration, and lower curtailment of renewable assets.

12.2 Flexible interconnectors are essential for the energy transition

Interconnectors and electricity grids are essential parts of the electricity system. Well-functioning and structured electricity grids are a key basis for a successful transition towards an energy system based on renewable energy. Robust transmission grids are needed to ensure electricity grid stability, market efficiency and RE integration.

There is no clear definition of when a transmission line is also called an interconnector. The general use of the word interconnector applies to a rather long transmission line from A to B, often between two systems that, which are asynchronous to each other, realised with High Voltage Direct Current technology (HVDC). These interconnectors and the transmission system as a whole have several important roles to play:[201]

- Low-cost interconnection over large distances. The costs of voltage transformation terminals at the end of HVDC links are more expensive than those for AC. However, the cost per kilometre of the line itself is lower. Over longer distances – approximately 600- 800km for current technologies – HVDC becomes the lowest-cost option.
- Connecting asynchronous grids. If two AC systems need to be connected, they have to be synchronised. They have to operate at the same voltage and frequency, which can be difficult to achieve. However, HVDC is asynchronous and thus can be adapted to any rated voltage and frequency it receives. That's why HVDC is used to connect large AC systems all around the world.
- Connecting remote energy resources and loads. If voltage of lines is increased, it becomes possible to economically connect more remote resources due to reduced line losses. Currently, high voltages systems with 800 kV and 1000 kV are becoming more common, which greatly reduces losses over long distances. An example of resources being located far from loads are wind resources in Northwest China and hydro resources in West China.
- Accommodating RE. The integration of RE requires flexible transmission links. One of the main drives behind the increased use of HVDC lines and interconnectors is the ability to transport RE to areas of high demand. This is important to integrate RE in the power system and market. A strong and large electricity grid using AC / DC lines and interconnectors over a large area helps to smooth the fluctuating generation pattern of RE.

Figure 12-1 illustrates as an example the forecasted need for large-scale transport capacities of electricity in Europe, which are needed for utilizing and integrating RE efficiently over a broad geographic range.

Figure 12-1: Need for European transmission grid capacities[202]

In this chapter, the situation of interconnectors and technologies used in China is discussed in section 12.3, and followed by the situation in Europe is described and the benefits of a flexible use of interconnectors are analysed based on a Danish case study in section 12.6., Section 12.7 illustrates experience with different grid layouts in Europe. Different use modes and their impacts on cost and market structures are modelled and analysed for China in section 12.8. The last section 12.9 of the chapter focuses on experiences with high voltage technologies in China.

12.3 Development status of inter-provincial power transmission lines in China

China's power generation resources and power load exhibit a distinct distribution pattern: coal power resources are mainly distributed in the Northeast, North Central and Northwest China, wind resources are mainly concentrated in these three northern regions and eastern coastal areas, and solar PV resources are mainly located in Northwest and northern parts of China. Load centres, however, are mainly concentrated in eastern and southeastern coastal and central regions. The uneven geographical location of China's electricity resources and demand has led to a system based on transmission of western electricity to eastern regions, mutual supply of northern and southern electricity, and nationwide electricity interconnection.

Figure 12-2: A schematic diagram of China's regional power grid division and the "West-East power transmission" project

Source: GIZ

As of year-end 2017, China has basically completed the construction of six major regional grid frameworks. The total length of transmission lines (220 kV or above) in the country has reached 688,000 kilometres, 30 times that of 1978, and substation capacity reached 4 billion kVA, 157 times that at the beginning of the reform and opening period. A total of 20 DC West-to-East power transmission channels have been completed to transmit electricity to the comparatively more developed eastern and central regions, making the country's cross-regional power transmission scale reach the level of 175 million kWh.

The scale of grid interconnection and electricity transaction with neighbouring countries has seen steady expansion. Accumulatively, 22 trans-national transmission lines were built to connect the country with neighbouring countries such as Russia, Mongolia, Kyrgyzstan, Myanmar, Laos, Vietnam, and others, with an annual electricity transaction amount of over 30 billion kWh. Under the Belt and Road Initiative, China continues to push forward grid infrastructure interconnection projects with neighbouring countries like Pakistan, Nepal, and Thailand. From 2006 to 2017, the amount of China's cross-regional power exchange increased five-fold, with the Southwest, Northwest and Central regions accounting for the biggest output power shares, which combined reach over three-quarters of the total. Of the 34 provinces and cities, 20 have a net output power of over 10 TWh; and 13 have a net input power of over 10 TWh. Yunnan and Sichuan, located in Southwest China with abundant hydropower resources, are the two provinces among with the largest shares of power export in provincial power output, both of which reached 40% in 2017. In contrast, Beijing and Shanghai – the most densely populated cities in China apart from Hong Kong and Macau – obtain more than 40% of their power supply from other provinces.

Figure 12-3: 2006-2017 Inter-regional power exchange

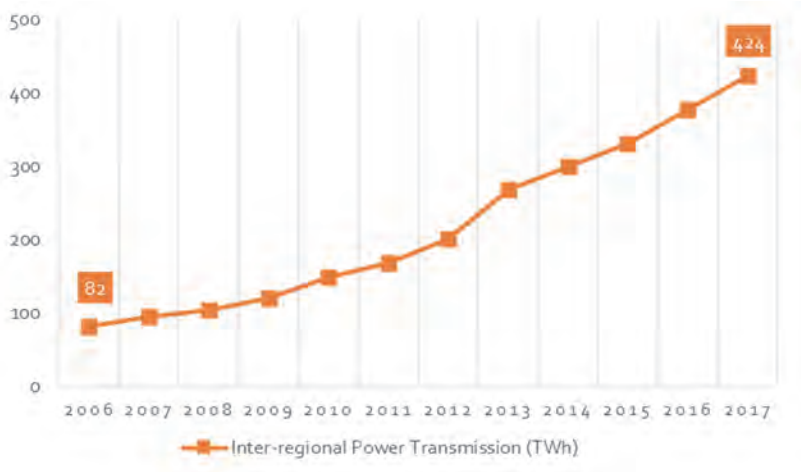
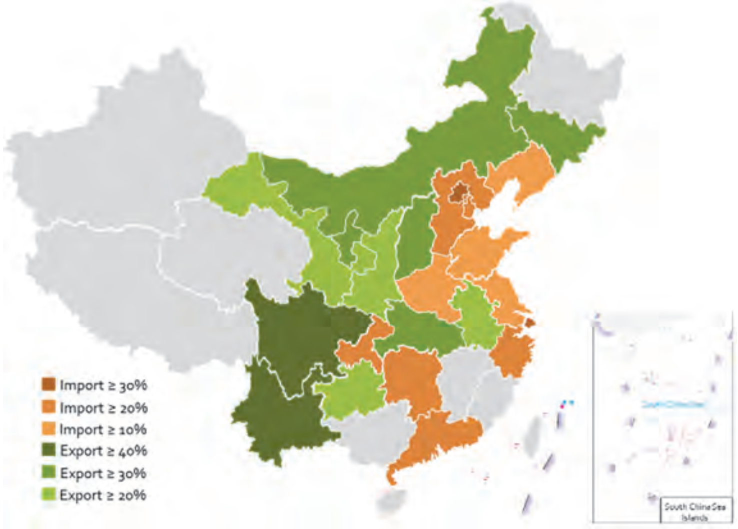


Figure 12-4: 2017 share of power export in provincial power output/ share of power import in provincial power consumption203



12.4 Main challenges in China

China's transmission system still suffers low utilization and resource efficiency

The uneven distribution of resources and demand makes transmission of electricity from the West to the East, exchange of electricity supply of northern and southern regions, and completing a nationwide grid network an inevitable choice for the country. However, since 2004, China's power grid development has been focused on large-capacity and long-distance UHV transmission projects. As a result, many existing 500-kV and 750-kV inter-provincial and inter-regional transmission lines have seen low utilization. This has resulted in the low efficiency in China's transmission line resource allocation. In 2016, the ratio of installed capacity to transmission line circuit length was about 2,638 kW per km in China, which was a 74.2% of the level of European power grid (2015), and 69.3% of the U.S. power grid (2012), and at a lower level than that of the Japanese and South Korean grids. If it reached the current utilization level of the U.S. power grid, China's current power grid will be sufficient to support additional 730 million kW of installed capacity. In 2016, the ratio of China's total electricity consumption to transmission line circuit length was 9.55 million kWh per km, barely 80% of European and U.S. utilization, and far from 22.91 million kWh per km and 15.22 million kWh per km, respectively, of Japan.

The implications are significant for future grid development: If China were to reach the current power transmission level of the U.S., for example, this implies the country's current transmission grid would support 7.8 trillion kWh of electricity consumption. This suggests no need for China to add any new transmission lines during the 13th Five-Year Plan period, at least in aggregate.

In addition, a large number of trans-regional UHV power transmission projects were launched in a rush when technology was not yet fully mature. The result is that some major power transmission projects failed to meet expectations on transmitting power during operation, with their reliability figures falling significantly below the national average. According to the Investment Result Supervision Report on Ten Typical Grid Engineering Projects Including Zhejiang-Fujian UHVAC Project recently released by the National Energy Administration (NEA), the maximum transmission capacity of the Hami-Zhengzhou Transmission Project has remained less than 63% of its design transmission capacity since it was put into operation.

China lacks flexible exchange across provinces and regions

China's power grid has long been operated under a planned scheduling system with little flexibility in cross-provincial or cross-regional electric power exchange. In contrast, countries, such as Denmark and Germany, where wind and solar power take up relatively large shares in electricity generation, benefit from flexible transmission line scheduling, which gives full play to the advantages of regional interconnections in peak shifting and shaving, as well as mutual backup. As shown in Figure 12-5, electric power and energy exchange between Germany and neighbouring countries shows high variability. Varying use of interconnectors provides an opportunity to reduce the impact of fluctuating power generation of wind and solar within the home country.

In contrast, as shown in Figure 12-6, China's operational model is incapable of making real-time adjustments based on the changing characteristics of the receiving and sending sides of the transmission channels. Rather, power flows are scheduled according to established power transmission curves. The distinct inflexibility in transmission corridor operations leads to low utilization rates for power grids. For example, in 2014, the maximum transmitting power of the Northwest Channel I and II's transmission section was barely one half of its design target, with its maximum utilization time being merely 970 hours. This low utilization also reflects the line's ineffectiveness in cross-provincial and cross-regional transfer of fluctuating wind and solar power.

Corridors in Beijing-Tianjin-Hebei (Jing-Jin-Ji) and Inner Mongolia are also good examples. Given the Jing-Jin-Ji region's 2015 installed capacity, with intra-regional balancing being the only option for the region, Jing-Jin-Ji not only faces a 15 GW power shortfall, and inadequate regulating capacity, but faces difficulties absorbing 5.4 GW of wind power. In contrast, Inner Mongolia has a surplus of nearly 80 GW of installed capacity and 12 GW of regulating resources. However, Inner Mongolia faces the baffling problem that if there is no outbound demand, 24 GW of wind power faces curtailment in valley load periods, and 14 GW of thermal power has to be shut down.

By tapping the flexible regulating potential of the Inner Mongolia-Beijing-Tianjin-Hebei 4-channel, 13-circuit 500-kV connecting lines and achieving grid interconnection among these regions, and without change the minimum output threshold of thermal power plants and the valley-peak difference, the combined region will have nearly 6.7 GW of surplus regulating capacity and enable grid connection of 6.7 GW of wind power, with various resources being utilized in an optimal manner. Therefore, the lack of flexible exchanges across provinces and regions has become an important bottleneck for the development of wind, solar and other renewable energy in China.

Figure 12-5: Electricity exchange with neighbouring countries in a day (24 hours) in Germany

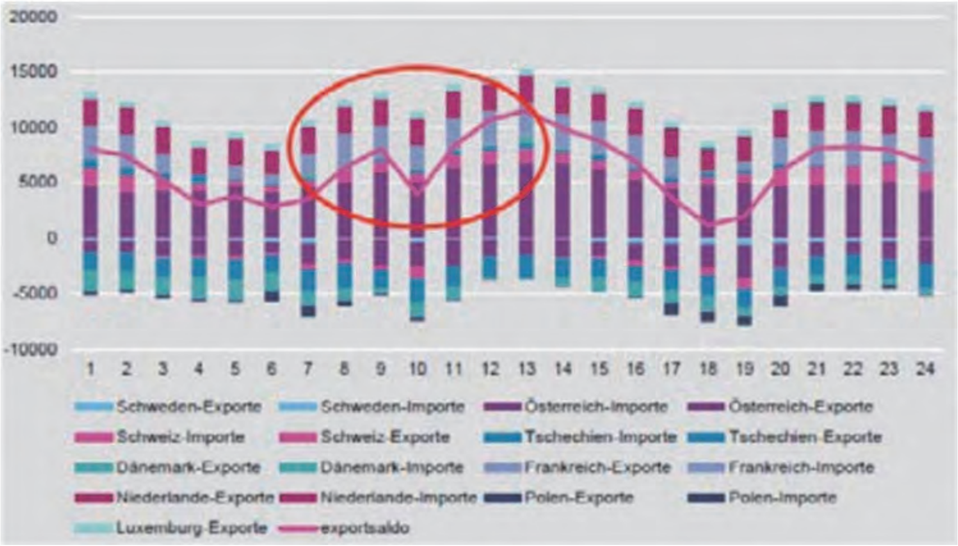
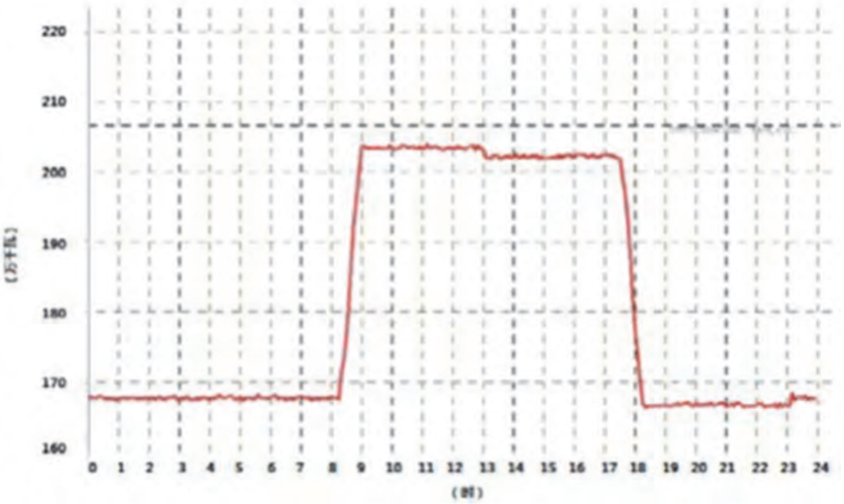


Figure 12-6: A DC monopolar transmission curve in China



Inter-provincial interest barriers remain

China's power grid development requires establishing a unified regional power market, marketization of cross-provincial and regional electricity trading, and promotion of power resource optimization and allocation in broader areas. The 2002 State Council Document No. 5 clearly setting the formation of open and competitive regional power markets as the goal of market construction; and the 2015 CPC Central Committee and State Council No. 9 Document and its supporting documents further stressing the need for improving cross-provincial and cross-regional power trading mechanisms. Nevertheless, provincial-level power grids still remain the main settlement and assessment entities for regional and national coordination and scheduling in China. Barriers to inter-provincial trading appear not only intact, but also show signs of worsening. This has resulted in the weakening of regional power grids.

Although flexible power grid operations help to deliver cheap hydro, wind, solar and other renewable-based power to meet the power needs of load centre across provinces and regions and achieve maximum social benefits, those provinces at the sending side, under the economic downward pressure and market carrying capacity, tend to sell high-priced electricity to other regions while taking low-priced electricity for themselves. In addition, provinces on the receiving side perceive that competition from low-priced electricity imports will worsen the financial position of local power generation enterprises. These issues, coupled with high transmission and distribution prices, make provincial officials and enterprises less willing to support flexible grid operations and electricity exchange. Therefore, the lack of flexibility in China's power grid operations at a deeper, non-technical level reflects the relationship between central and local interests. Inter-provincial interest barriers have become one of the main constraints affecting the flexibility of power grids.

Optimization of investment and development are still needed

China's power grids are mainly planned by the government, and mostly invested and built by power grid companies. EHV and UHV power grids owners, most of which are used as channels for dispatching cross-provincial or cross-regional resources, are concerned to recover investment in power grid construction, while ensuring supply is matched with the load at receiving and sending sides. Given they earn fixed transmission and distribution prices, power grid companies lack incentive for flexible operation; instead, they run power plans at full load in the hope of quickly recovering their investment costs. In other countries such as Denmark, with flexible tie-line operations, the planning and construction of tie-lines is fully integrated into the receiver-side planning. The investment and construction of power grid lines take place after full considerations for the overall economic benefits of power generation, transmission, and demand, as well as to issues regarding whether or not such a move is compliant with the norms of power market operations.

Therefore, China's power grid, especially tie-line planning and construction, lags in relation to the assessment of supply and demand at sending and receiving sides, and market integration. There is also a gap in overall optimization of power generation, transmission and demand. Power grid owners are more concerned about recovering their investment, rather than ensuring the maximum benefits for the whole society. In the meantime, the lack in overall optimization of investment and construction with the supply and demand market constitutes a major factor affecting power grid flexibility.

12.5 Outlook on China’s power grid development and planning

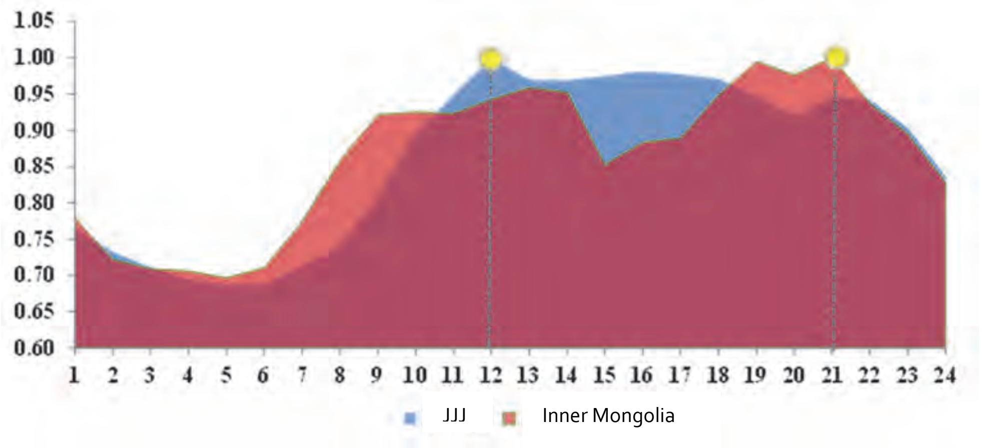
After several decades of incessant efforts, China's power grids have witnessed rapid growth at all levels. This includes 500 kV (750 kV in Northwest China) UHV trunk networks covering basically all Chinese provinces and municipalities, and a national interconnected network gradually taking shape across the country. China's power grid resource allocation has mainly demonstrated a pattern of transmission of electricity from West to East, mutual supply of northern and southern electricity, and nationwide electricity interconnection. Nevertheless, realizing more efficient deployment of power resources across a broader area still remains a focal point for discussion.

From a technical point of view, due to the limited system stability of 500-kV AC transmission, its transmission distance should ideally not exceed 1100 km. Whereas for 1000-kV AC transmission, the transmission distance can go beyond 2000 km. Under the same condition of 3000 MW transmission capacity, based on the unit capacity cost and annual operating cost, if transmission distance is less than 1100 km, 500-kV AC transmission has a significant cost advantage over 1000-kV AC transmission in terms of estimated construction and operating costs.

At present, however, the distance between most Chinese provinces and regions is generally less than 1000 km. Although a relatively complete 500-kV (750-kV in Northwest China) UHV transmission channel network now connects China’s different provincial and regional power grids, these UHV transmission channels remain under-utilized. Taking the interconnection of Beijing-Tianjin-Hebei Region and Inner Mongolia as an example, given the geographical extent of the Beijing-Tianjin-Hebei Region and Inner Mongolia, the length of an interconnection project would generally not exceed 1000 km. Given the cross-provincial multi-infeed 500-kV UHV transmission network already in place between the two regions, Inner Mongolia's abundant renewable-based electricity can be delivered by the nearby UHV transmission network to load centres of the Beijing-Tianjin-Hebei region, hence achieving greater economic efficiency.

In addition, taking advantage of the load time disparity of different regions would result in more efficient utilization of grid resources. For instance, a summer peak in the Beijing-Tianjin-Hebei Region often appear from 10:00 to 12:00 in the morning, while Inner Mongolia typically has a system peak from 17:00 to 21:00 in the evening. Electricity exchange in an interconnected network would effectively reduce the need for building new generation and grid assets, thus helping to achieve more efficient use of grid resources. Therefore, China must, whilst adhering to the principle of utilizing electric power locally, vigorously promote uninterrupted cross-provincial and cross-regional power transmission, and make full use of existing inter-provincial/regional 500-kV or 750-kV power transmission lines. China should also implement a layer-by-layer power dispatch system where inter-province balancing, as a priority, always comes first, followed by coordinated regional balancing and then centralized national balancing. This would lay equal stress on centralized and decentralized utilization of various types of power generation resources, to promote power consumption both locally and across different regions, and advance the optimization of clean energy across a broader geographical area.

Figure 12-7: Loads in a typical summer day in Jing-Jin-Ji (blue) and Inner Mongolia (red)



12.6 The use of interconnectors in the coupled European power market

The main driver for transmission development in Europe is the integration of renewable energy sources, primarily wind power and PV. The goal is to make a complete transition of the current fossil-based power system towards a sustainable energy system with high shares of RE. This is necessary to combat climate change and to achieve the European emission reduction target for 2050 of 80-95% reduction of CO_2 emission below 1990 levels by 2050.

Figure 12-8: Present European transmission system, AC and DC transmission lines. (Legend: green lines indicate transmission at 220 kV; red lines indicate transmission at 400 kV). [204]

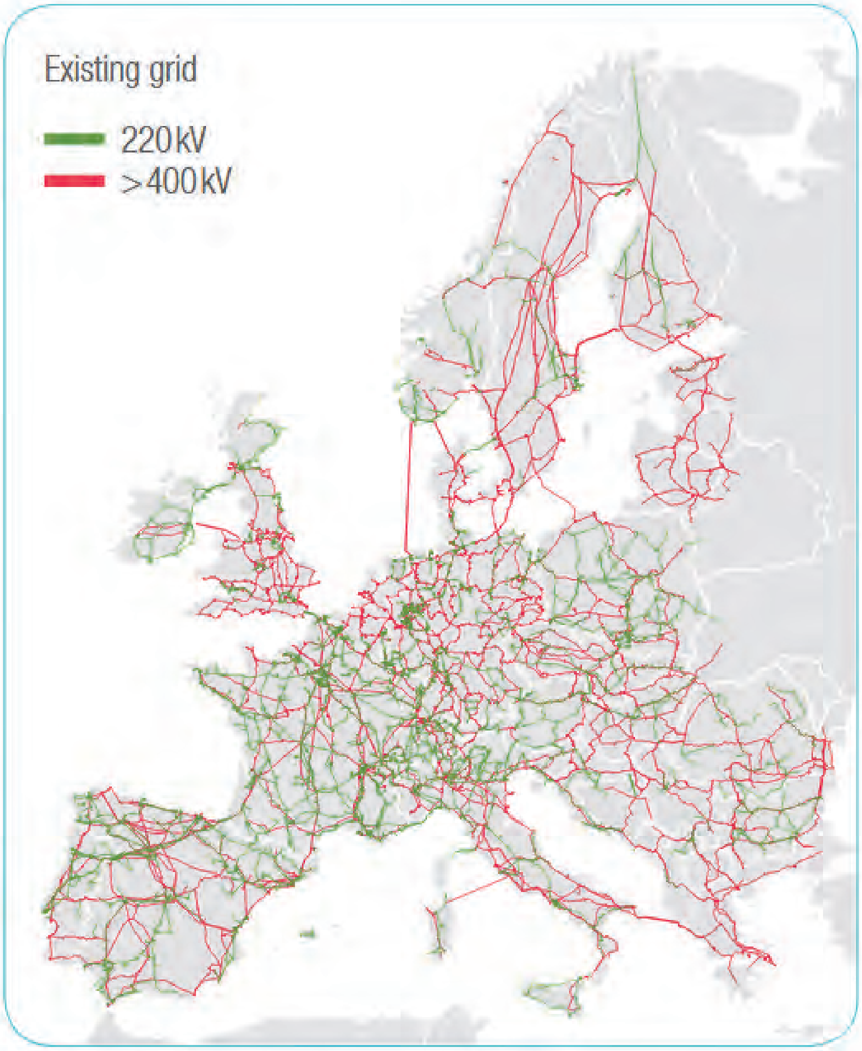


Figure 12-8 shows the present European transmission system for voltage levels of 220 kV and above. Today, Europe encompasses five systems: The Central European System which is the biggest subsystem that comprises 24 European and North African countries, the Nordic System, the Baltic system (part of the IPS/UPS system with Russia and Belarus) and Great Britain and Ireland as island systems.

Aside from AC transmission lines, Europe has several high-voltage DC transmission lines. DC technology is used at so-called border connection points, for connecting different synchronous systems. [205]

DC is also used to connect two points (substations) in a grid that are far apart from each other or if the connection is via a long subsea cable. The rationale is to reduce transmission losses and increase transport capacity: a long AC cable at high voltage generates a high amount of reactive power which reduces the cable's transport capability of active power. While transmission lines are the technical hardware that makes it physically possible to transport electricity, power markets are the functional base where trading activities define how the flows in the transmission system will be directed with regard to the physical laws and constraints.

The electricity market in Europe consists of a suite of markets as depicted in Figure12-9:

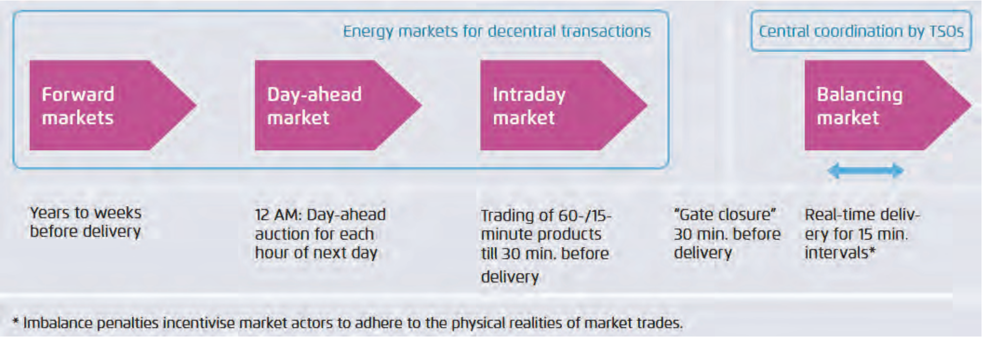
- The **forward market** for electricity is similar to the financial markets for bonds, stock and currencies. The objective of this market is to hedge the risk of future electricity prices for buying or selling electricity. For that purpose, the stakeholders in the market can buy and sell electricity volumes in the forward market.
- Generation and transmission scheduling in Europe takes place primarily in the price-coupled integrated European **day-ahead markets**. In these markets the bids are given to the power exchange each day before noon for the succeeding calendar day.
- The **intraday market** opens for trading after the day-ahead market has been cleared. Intraday-market is open until about 1 hour before fulfilment of the order. The purpose of intraday trading is to make it possible for market participants to trade and thereby make corrections to their positions in the market before fulfilment.
- The **balancing market** is operated by the TSOs. The TSOs procure frequency reserves and buy balancing power in the balancing market to create balance in their respective balancing area and ensure system stability of the electricity grid. Frequency reserve can be bought in three product qualities, primary, secondary and tertiary reserve, via a market-based auction process. Potential providers are subjected to a prequalification process before being able to participate and need to prove that the planned generation units or flexible loads have the required availability, reliability and controllability.[206]

Due to its large trading volume the **day-ahead market** is currently the largest and most important market for interconnectors. In Europe, interconnectors are used to connect different electricity markets. The interconnectors are utilized according to market signals like price differences and signals from the day-ahead power market, so electricity can be traded from one electricity market to the other. Capacity and reliability constraints are limiting factors to the trading activities.

In the future with increasing amount of RE in the power system the **intraday market and balancing market** will become more and more important due to the fluctuating character of RE. The shorter the timespan to the physical delivery of electricity, the better is the quality of the RE generation forecast. The economic efficiency of the overall system increases if the trading occurs closer to the time point of physical delivery like in the intraday market. So it is expected that volume of electricity traded in the intraday market will further increase in the future also due to increasing possibilities of digitalisation and automated trading.

Due to the fluctuating generation of RE, the need of **balancing power** might increase as well to ensure system stability of the power grid.[207] Recent developments and trends in market activities show that shorter trading times or even real-time trading have the potential to address and limit this risk.

Figure 12-9: Sequence of market based transaction in the European power market[208]



* Imbalance penalties incentivise market actors to adhere to the physical realities of market trades.

Figure 12-10: Physical flows (GWh/year) on European interconnectors in 2016 [209]

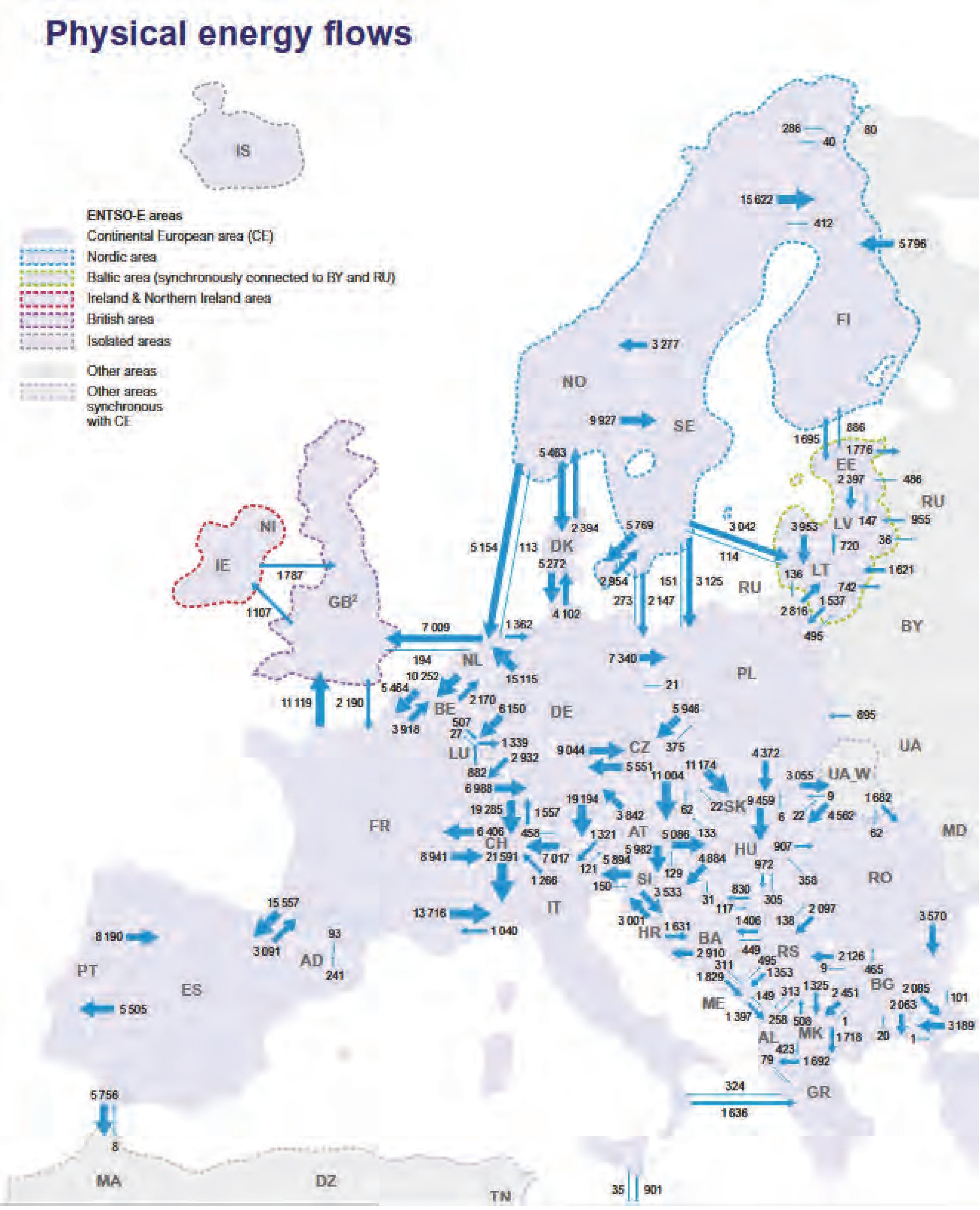


Figure 12-10 presents the overview of the physical energy flows of interconnectors in Europe in 2016. The sum of imports and exports for each country are also provided. For example, the figure shows high imports to Denmark and high exports from Germany in 2016. Another major electricity flow is traded from Norway over Denmark and Germany to Italy, which shows a strong need for electricity trade and supply from the north of Europe to the south due to lower installed generation capacities (compared to the demand) in the south of Europe.

Current challenges of available transmission capacities for trade

ENTSO-E and other European TSOs are working on optimizing cross-zonal interconnector capacities in order to enable electricity trade and exchange between the national markets or market zones whenever they are triggered by market price differences. [210] When determining the cross-zonal capacities, TSOs must also consider the secure operation of the power system. Where cross-zonal capacities are constrained, investments in transmission should be undertaken if they prove to bear socio-economic benefits. As a short-term measure, re-dispatching and countertrade are used by TSOs to address cross-zonal capacity bottlenecks, as long as this is socio-economically beneficial and the operation of the system is still secure.

National regulatory authorities (NRAs) have the task to monitor the interconnector capacity calculation process to ensure that the cross zonal capacities represent the optimal trade–off between market needs and security of supply. NRAs also oversee if appropriate development and investment in new transmission lines take place. ACER (Agency for the Cooperation of Energy Regulators) has recently published a monitoring report in which it criticizes the process how TSOs handle the cross-zonal capacity allocation[211]. ACER claims that the amount of capacity given to the market could be higher and argues that there are two key reasons for the constraints:

- The process used to calculate the capacity made available for cross zonal trade is insufficiently coordinated among the TSOs.
- TSOs tend to prioritise internal transmission within the zones over cross-zonal exchanges – that is, they regularly limit cross-border capacity to relieve internal congestion.

These topics are being analysed at the moment by several institutes. ACER might act on this on a later point in time having more profound information to base a decision on. This topic is part of the “Clean Energy for all Europeans” package (see Part 1 Chapter 2 for more information), which is currently in discussion. The question is how much priority should be given to market versus system security issues.

Decreased flexible interconnectors leads to socio-economic losses

To support the development towards more flexible power systems to support RE integration, a deep and detailed understanding is needed on the value and effect of different flexibility options. Flexibility options are: grid extension, thermal power plant flexibility, demand side management and storage.

A case study published by the Danish Energy Agency serves this purpose.[212] Based on model analyses, the study analyses the value of flexibility measures in the Danish power system. The measures investigated are flexible power plants and flexible use of interconnectors to neighbouring power systems. The analyses have been conducted by the Danish TSO Energinet for DEA (Danish Energy Agency). The model analyses were carried out by Energinet's in-house model named SIFRE (Simulation of Flexible and Renewable Energy systems). This simulation tool is able to analyse spot markets of energy systems with several generation technologies including combined heat and power (CHP) to generate heat and power. The model conducts simulations with an hourly time resolution. And it includes great detail of fuel consumption of multiple energy generation types and which are connected to electricity grids.

The choice of using Denmark for illustration of flexibility needs and flexibility sources is quite obvious as Denmark has the world highest share of variable renewables wind and solar in the power system. In 2017 wind contributed with about 44% of total Danish electricity consumption, whereas solar PV contributed about 2%. Danish wind generation exceeds domestic electricity demand in 5% of hours over the year. Denmark is one of the countries in Europe with the highest international interconnection capacities. The total interconnector capacity to Norway, Sweden and Germany amounts to about 6,000 MW, which is about 50 % of the total installed generation capacity in Denmark.

The model analyses different scenarios in order to evaluate the consequences of reducing the flexibility of the power system compared to the present system in 2018, which constitutes the base case. Unless otherwise stated all presented results are yearly values or yearly averages.

Scenario results

The base case scenario being the present Danish power system is characterized by having very flexible thermal power plants and a high degree of flexibility in balancing via strong interconnections to neighbour countries.

One other scenario has focus on reducing the system's flexibility by significantly reducing the capacity of interconnectors to the neighbour countries. A reduction of 80% on all capacities has been assumed, thereby reducing the total exchange capacity to about 10% of the total Danish generation capacity. 10% is the European Commission's overall minimum target for 2020 for EU countries.

The most important effects of **reduced interconnector capacities** compared to the base case are:

- While the curtailment is practically zero in the base case, it will increase significantly to about 9% of potential generation of wind and PV. 99% of the curtailed energy will be wind power.
- The prices in wholesale markets would decline substantially for all Danish stakeholders being studied. Exemplary and most pronounced is the 30% reduction for wind. The

price reduction plus the curtailment leads to an overall reduction in economic surplus for wind at about 20%.

- The large thermal power plants using conventional fuels produce about 10 % more with a lower efficiency and a 2% lower price which is leading to a decline in economic result compared to the base case.
- The system overall CO_2 emissions increase about 7%, mainly due to increased CO_2 emissions from large thermal power plants.
- The overall socio-economic result for Denmark (of producers, consumers and congestion rents) amount to a yearly loss of approximately Euro 170 million. In comparison and exemplary, the total revenue for 5 GW wind in the wholesale market is about Euro 350 million in base case.

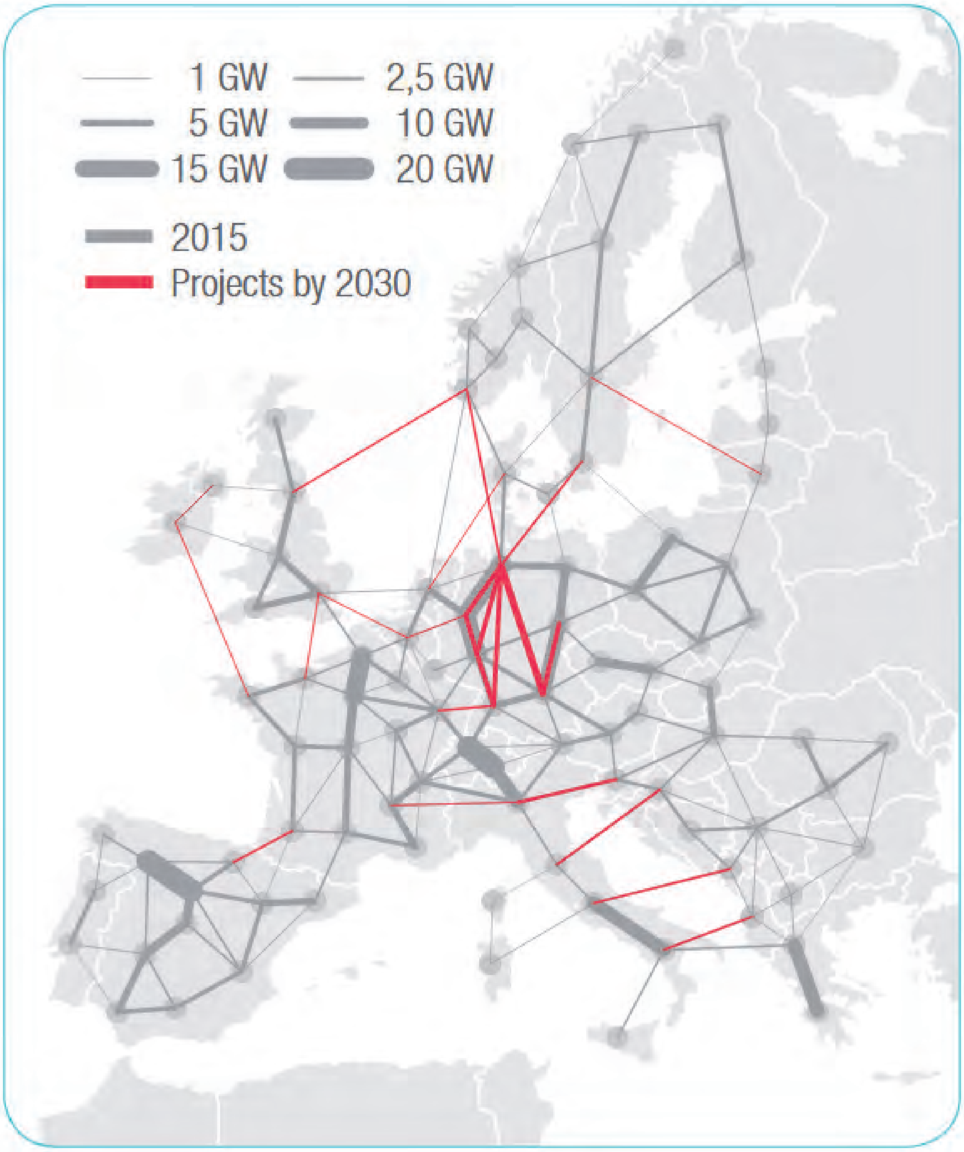
It can be concluded that Danish interconnector capacity is pivotal to integration of wind. Without sufficient exchange capacity, the system value and market price obtained by wind will deteriorate and there will be no or a less positive business case for wind power investors. Also the economic results for the large thermal power plants will be reduced.[213]

12.7 European experiences with different grid layouts

The present European transmission grid was illustrated in Figure 12-8. An equivalent model of the grid is shown in Figure 12-11

The figure includes present transmission lines and planned projects according to ENTSO-E Ten Year Network Development Plan results by 2030. [214] Overall, the European transmission system is highly meshed in Central Europe and that Central Europe is connected with the surrounding countries/areas by corridors which are less meshed. One example is the corridor from Scandinavia to Central Europe. The vision of a Europe-wide grid goes back at least to the 1920s, but its advantages gained even more importance as Europe was rebuilt after World War II. Interconnecting electric power systems can make power less expensive and more reliable, conserve resources, and reduce emissions and pollution – particularly when energy inputs come from variable sources, such as run-of-river generators, hydropower dams and thermal power stations.

Figure 12-11: Equivalent model of European transmission grid in 2015 including projects by 2030[215]



The output of run-of-the-river power plants varies with river flow. The output from dams is constrained by the flow from the rivers behind, the water needs of downstream users, and the need to protect downstream land from flooding. An optimal hydrothermal mix allows reduction in thermal-plant output when hydropower is plentiful, conserving fuel and reducing fossil-fuelled power production. Furthermore, during low load periods, thermal power can be used to pump water back into reservoirs, for use during dry spells or to ensure adequate power during peak load—in effect, sharing reserves to increase reliability while reducing costs.[216]

Experiences with point-to-point connections

Experiences with point-to-point connections in Europe have been gathered since 1960-ties. The first HVDC (High Voltage Direct Current) link as interconnector between two countries in the world was constructed between Denmark and Sweden in 1965 (Kontiskan). The line is a point-to-point connection between two synchronous systems, the Nordic system and the Central European system. Since then, many HVDC connections have been built which were by definition point-to-point connections, because converters are needed at both end of the power line.

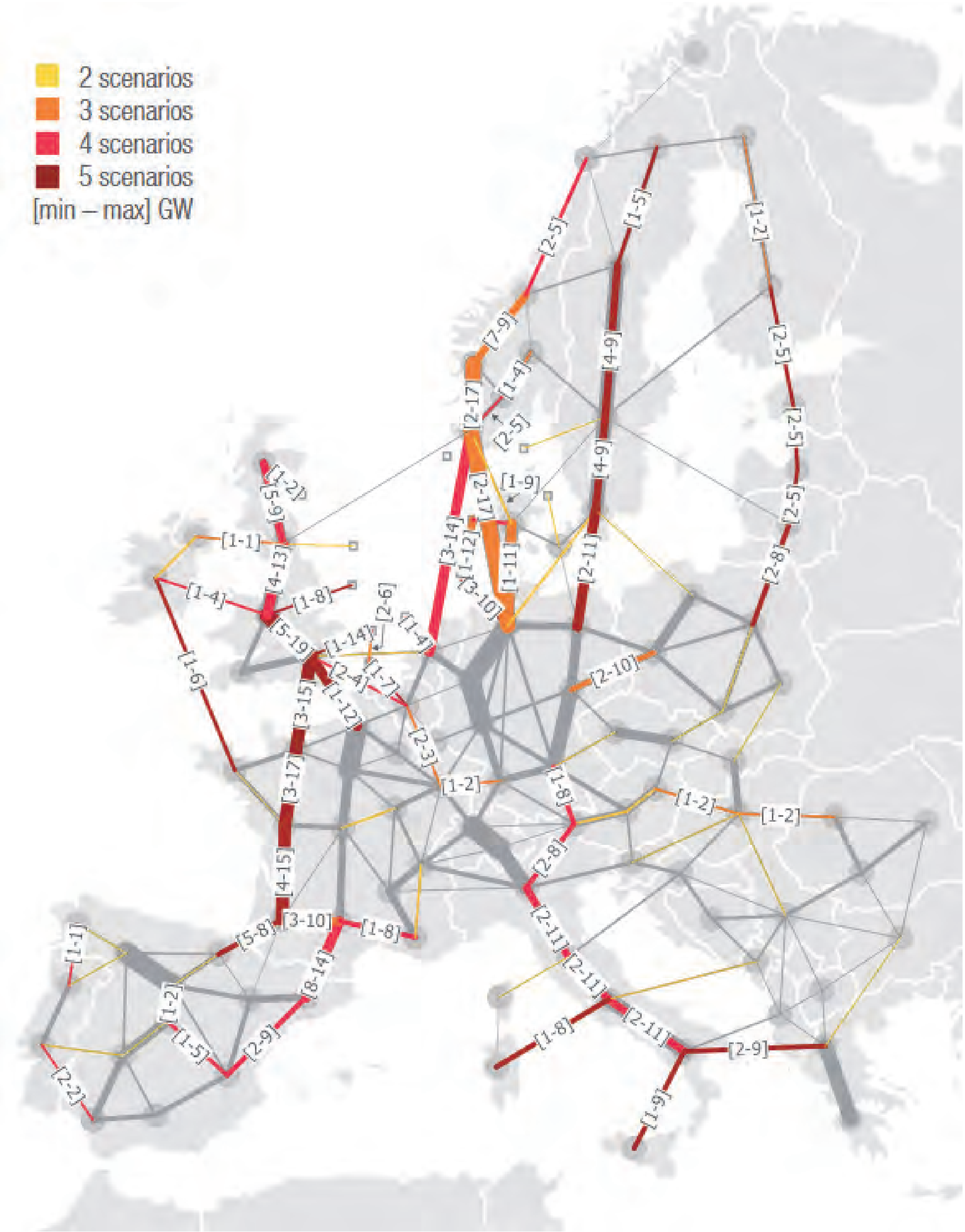
Point-to-point connections can be economically and technically viable when the distance between the end points is long, even if the end points belong to the same synchronous system. An example is the 350 km long connection between Denmark and the Netherlands with 700 MW DC capacity, which will come into operation in 2019. The reason for choosing DC is to limit the electrical losses and for constructing a new corridor, due to overloading of the existing meshed AC grid that connects Denmark with the Netherlands through Germany.

Interconnecting Europe: Is there a need for supergrid structures? Results of the EU-project e-Highways 2050

The EU-financed project *e-Highways 2050* set up different architectures for the future European transmission system for different future scenarios towards 2050. All scenarios had to comply with the European CO_2 emission reduction targets of 80-95 % below 1990 levels by 2050. The study analysed which grid layout, technologies and grid extensions are needed for a low carbon energy system in 2050. Furthermore, the study analysed whether a new, over-arching high-voltage layer of DC-lines within the existing transmission network, or super-grid, would reduce overall system cost and improve system stability.

Figure 12-12 indicates a synthesis of results of grid infrastructures in the 5 different chosen scenarios for 2050: different generation fleets, generation technologies, demand development, and utilization of demand response. Only the reinforcements occurring in at least two of the five scenarios are shown. The widths of the lines are according to average reinforcement capacity and the colour represents the number of the five scenarios where the reinforcement is needed. The numbers indicate min-max reinforcement capacities in GW.[217]

Figure 12-12: Synthesis grid infrastructure results of European wide assessment for 2050 [218]



An invariant set of transmission reinforcements has been found in the five scenarios. Major North-South corridors appear in all scenarios with several reinforcements that connect the north of the pan-European electricity system (Scandinavia, UK, Ireland), and the southern countries (Spain and Italy) to the central continental area (Germany, Poland, France). The major common corridors can be summarized as follows:

- Corridor from Great Britain and Ireland to Spain through France. The connections from Ireland to Great Britain and from Great Britain to France are point-to-point DC connections between different synchronous systems.
- Corridor from Greece to Italy and the Italian backbone.
- Corridor from Norway and Sweden to Continental Europe Norway and UK. This corridor includes point-to-point DC connections between different synchronous systems.
- Corridor from Finland to Poland through the Baltic States. The corridor includes connections of three different synchronous systems (Finland, Baltics, Poland).

The study concludes that the present and future European transmission system should be described as a highly meshed AC system in Central Europe with connections to groups of countries in the North and South which are not meshed. These connections are flexible point-to-point DC connections that are dispatched according to market signals in case transfer of large power flows is needed, in case the connection is between two different synchronous systems, or if the existing meshed AC grid is congested.

The main conclusion of the project is that a new ultra-high-voltage DC-grid layer is not needed. Targeted DC-based grid enforcement between the crucial corridors are recommended. [219]

12.8 Flexible use of interconnectors in China leads to lower overall system costs

A market-based dispatch of interconnectors (see chapter 11.4 "Grid development" of CREO 2017 for detailed explanations) has a clear influence on transitioning to a beautiful and green China as the model results below show. A fixed inflexible interconnector dispatch has a higher need for dispatchable power generation, such as coal power generation, but also storage technologies to balance the system. Using electricity markets to dispatch interconnectors leads to lower total CO_2-emissions because the curtailment of variable RE will decrease. This leads to a higher RE portion in the electricity mix and helps to reduce the dependency on coal power generation.

Modelling results of a market-based dispatch of interconnectors

If interconnectors are dispatched in a dynamic way according to market signals, they provide flexibility by allowing RE generation to be transmitted to other regions in case they provide a low-cost price signal instead of being curtailed. The modelling results show, that a highly interconnected electricity system comes with higher upfront grid investment cost, but this is outweighed by the overall higher system efficiency and the socio-economic benefits that can be derived from an integrated and market-based operation mode.

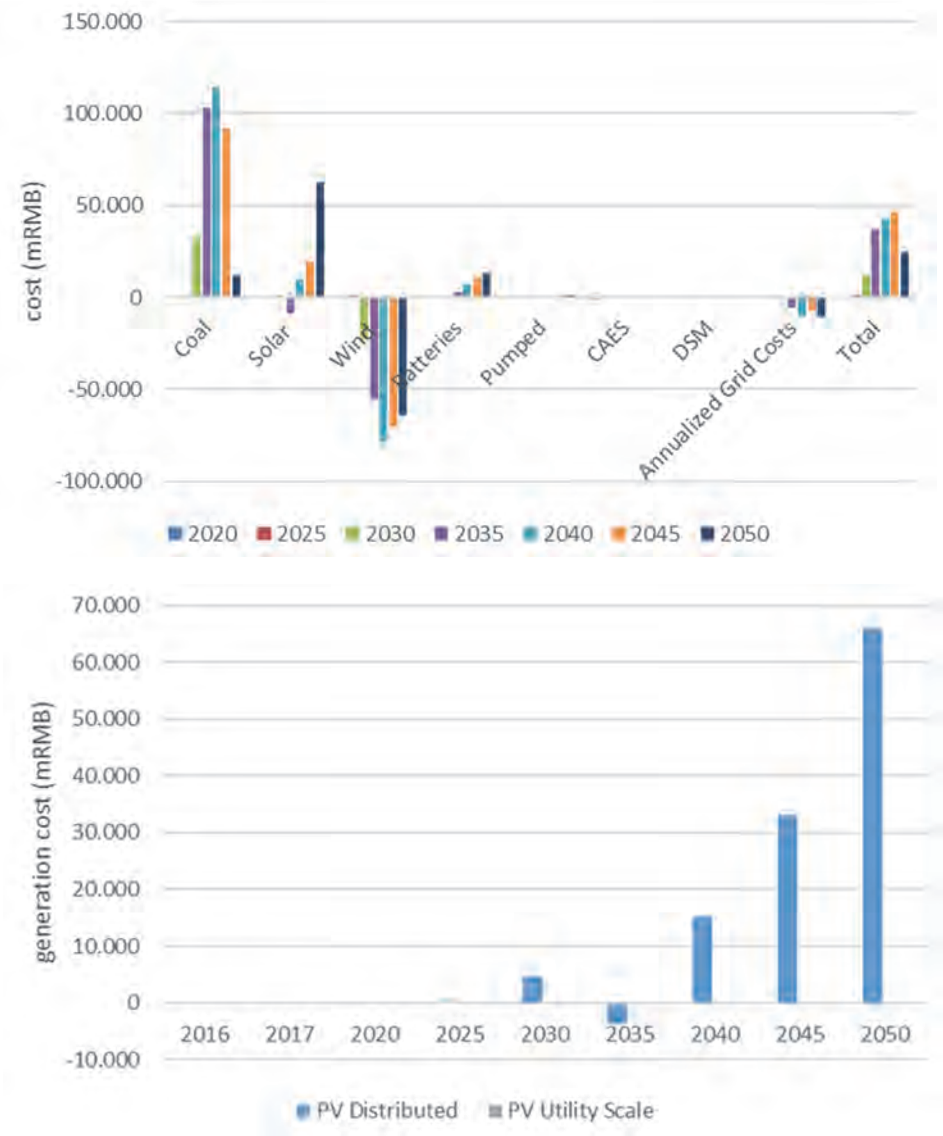
The EDO-model was used to compare one of the two main scenarios of CREO 2018 (Stated Policies) with one variation assuming a continued, inflexible dispatch of interconnectors. The variation illustrates the use of interconnectors between regions based on a fix and pre-determined dispatch like it is common in China nowadays. "Fixed" in this case means that the transmission capacity will be set to one level during the day and another during the night. For instance, the transmission on one interconnector could be 2 GW in each hour between 8 am and 8 pm and 1 GW in each hour between 8 pm and 8 am.

In the stated policy scenario, it is assumed that regional and provincial markets are fully introduced and interconnectors are used in a flexible way. Interconnector capacity utilization is dispatched according to market-based principles and can therefore change for each hour. In both scenarios, expansions of the electricity grid are performed by the model according to an overall cost and benefit analysis (CBA). Where necessary, grid constraints and bottlenecks are also considered. The model assumes a market-based dispatch of generation in both cases, but differentiates for the interconnectors. The overall policy targets and constraints will be fulfilled in both cases, including CO_2 targets.

Figure 12-13 shows the difference of total generation cost and annualized grid costs of the two scenarios with SP Flexible Grid as the base case, represented by the x-axis and the deviation by SP Inflexible Grid depicted by the columns for various modelled years. SP Inflexible Grid has higher overall cost; the grid investment cost are lower but the generation cost are higher due to a higher utilization of coal, solar and batteries.

The increased interconnector investoment cost in SP Flexible Grid are outweighed by the decrease in cost of additional RE and coal generation. These cost include variable cost and fixed cost. That means financial cost are included. Due to the inflexible grid, wind power can only be used in limited amounts and accordingly the generation costs of wind (as the sum of cost for all integrated kWh of wind) are significantly lower in SP Inflexible Grid. That means, due to lower wind power generation volumes with lower specific cost compared to coal, more expensive generation technologies like coal have to be used, which leads to higher total operation cost. Furthermore, a market-based dispatch of interconnectors will benefit investments in interconnector capacity, which in turn allows for further integration of RE, lower generation costs, and lower socio-economic costs.

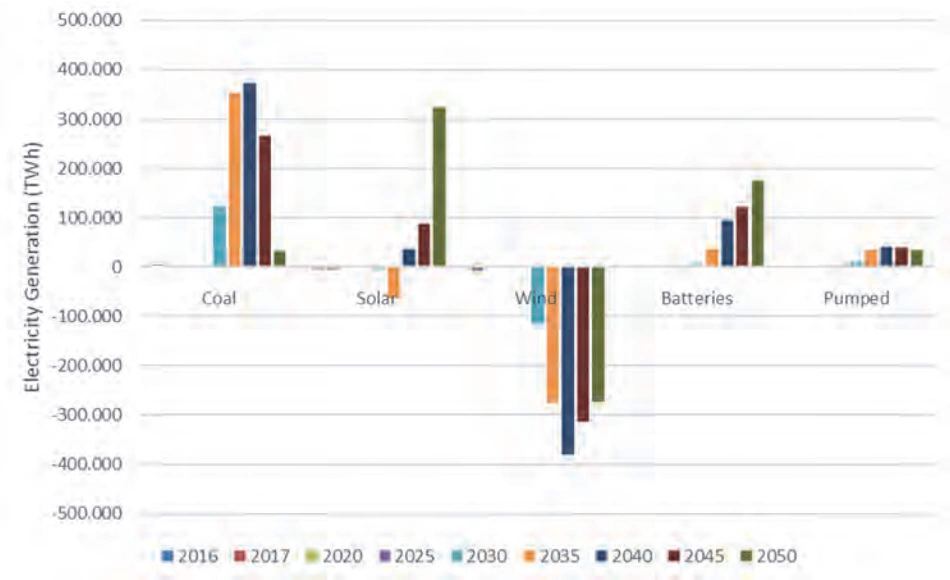
Figure 12-13: Difference of generation cost and annualized grid costs of SP Inflexible Grid compared to SP Flexible Grid



Correspondingly, grid investments in the model variation SP Inflexible Grid are lower since inflexible interconnectors provide less benefits to the power system than flexible interconnectors and are therefore not built (see Figure 12-13)

The missing flexibility in SP Inflexible Grid leads to a higher utilization of all generation and storage technologies as depicted in Figure 12-14. Furthermore SP inflexible grid leads to higher generation cost of electricity by PV instead of wind, since more distributed solar is used, and constructed closer to load centres (see Figure 12-15). Especially in 2050, PV generation is used to substitute coal power generation in order achieve emission reduction goals (see Figure 12-14).

Figure 12-14: Difference of electricity generation of SP Inflexible Grid compared to SP Flexible Grid



With regard to installed capacities, more coal power capacity is needed in SP Inflexible Grid to balance the grid and the installed wind capacity is much lower than in SP Flexible Grid because the grid is not able to transmit wind power from regions with high wind potential towards demand-intense regions. This is to some extent compensated by a higher capacity of solar power (see Figure 12-15, Figure 12-16).

Figure 12-15: Differences of installed power generation capacities between SP Inflexible Grid compared to SP Flexible Grid (of solar, wind and coal

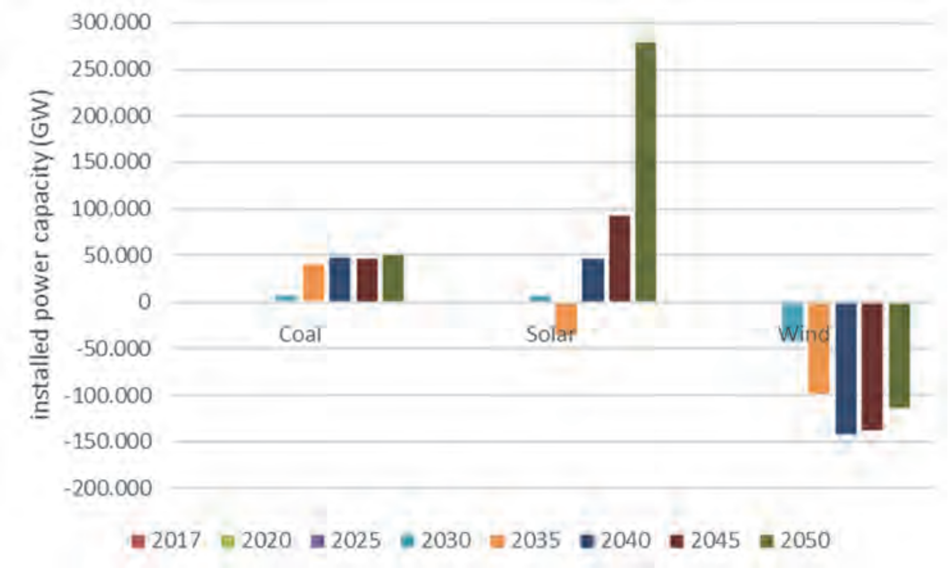
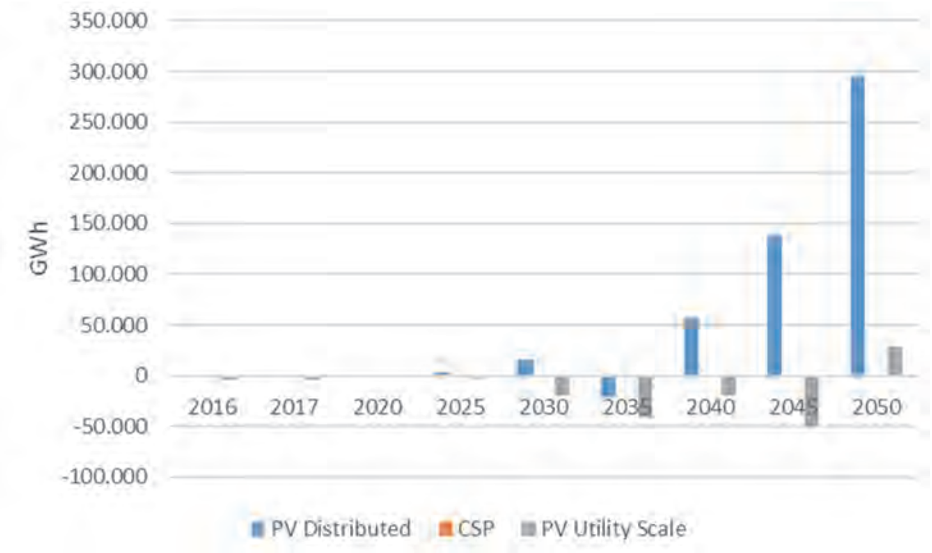
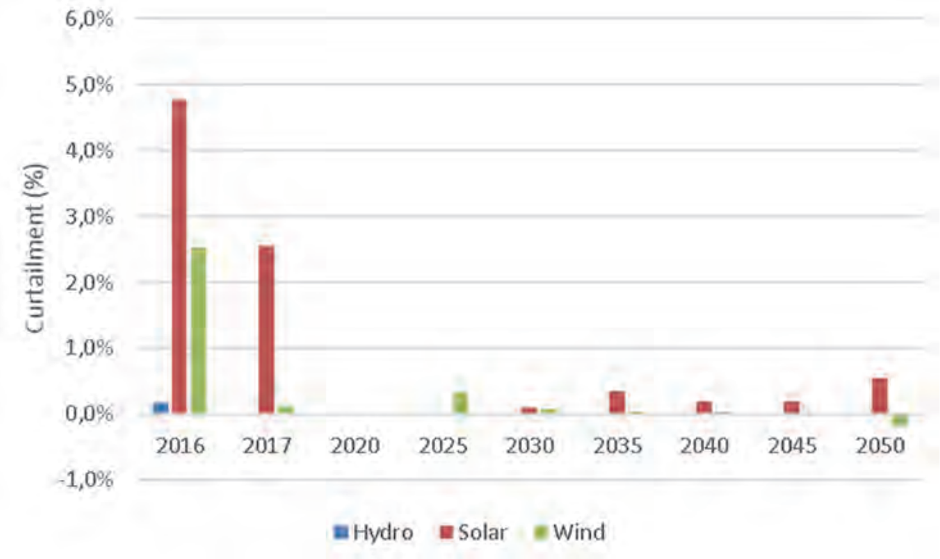


Figure 12-16: generation of PV distributed and PV Utility Scale



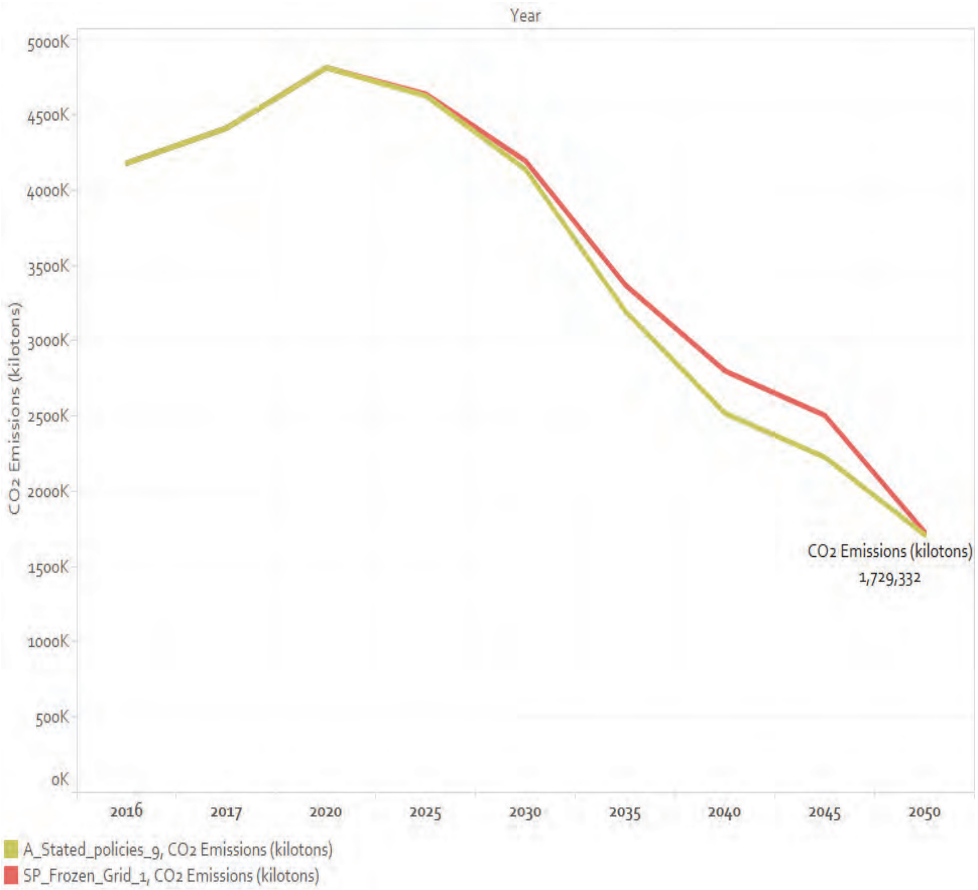
SP inflexibel grid leads generally to higher curtailment rates (see Figure 12-17) and lower wind penetration compared to SP Flexible Grid, as depicted in Figure. One of the influence factors is the interconnectors having a pre-fixed power flow where the dispatch doesn't consider the economic benefits of dispatching according to generation costs. In this case, generation cost would be optimized and lower, using an cost-optimized portfolio of generation technologies. Especially in the first modeling point, and the year 2017, the difference of curtailment rates are high. But even in 2040, 2045 and 2050, SP Inflexible Grid has a significant higher curtailment rate of solar power compared to SP Flexible Grid. This means technologies with higher cost and presumably with higher emission profiles have to be used.

Figure 12-17: Differences of curtailment rates for hydro, solar and wind power of SP Inflexible Grid compared to SP Flexible Grid.



That leads to higher overall CO_2-emissions in a path towards 2050 for SP Inflexible Grid (see Figure 12-18). However, the CO_2 emissions for SP Flexible Grid per year will only be slightly lower in 2050 as the fossil power generation is only slightly higher in SP Inflexible Grids (see Figure 12-14). That means the effect of market-based dispatch of interconnectors is fully utilized and further mitigation options are used to lower CO_2 emissions to the level required by the Paris agreement.

Figure 12-18: CO_2 emissions towards 2050 for both main scenarios and variants.



Overall cumulated CO_2 emissions are 2.6 % lower with a flexible usage of interconnectors
The modelling results show that SP Flexible Grid leads to lower CO_2 emissions and lower overall system cost. The overall system cost in SP Inflexible Grid is about RMB 245 million higher compared to SP Flexible Grid. This is about 0.8% of total system cost of SP Flexible Grid.

12.9 Improving interconnection in China using existing HVDC infrastructure

Due to high economic growth in recent years and corresponding high energy demand growth, China rapidly expanded its electricity infrastructure to supply this energy. One approach was to build long-distance HVDC lines to deliver electricity in demand centres from locations with high electricity surplus due to conventional power plant capacity or high RE potential.

Benefits of High Voltage lines

The HVDC transmission lines have several benefits over High Voltage Alternating Current (HVAC) transmissions. First of all, there are no technical limitations for transmission distances, especially for cable-connected systems. The maximum cable distance for the HVAC is about 80-100 km; application of HVAC technology may become difficult to implement because large amounts of reactive power compensation are required. Secondly, smaller losses in conductors for HVDC lead to higher power transfer capabilities than HVAC. Thirdly, some configurations of the HVDC have partial power transmission possibilities even when one of the conductors is disconnected. Compared to HVAC, where this is not possible at all, this contains the potential for much more flexible operation modes. Furthermore, HVDC can be used to interconnect asynchronous AC networks. Finally, fast and accurate controllability of the active power is achieved using HVDC systems.

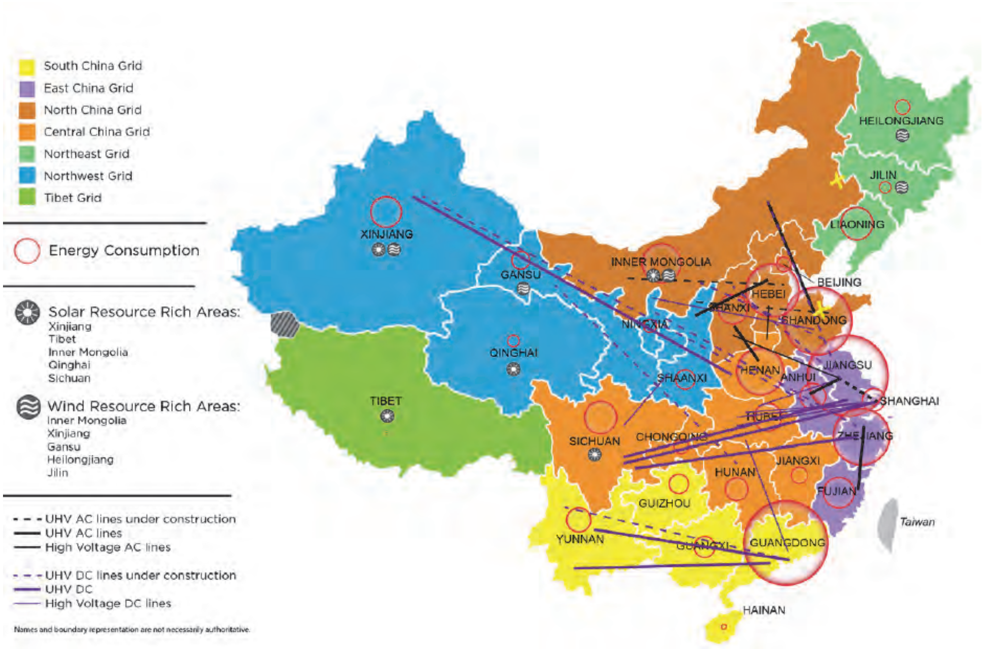
Status Quo of High Voltage lines in China

In China, a large number of HVDC projects have been constructed to integrate diverse power generation sources into the electricity grid, see Figure 12-19. The figure only shows Ultra-High Voltage Direct Current (UHVDC) connections in the northern china grid controlled by State Grid Cooperation of China (SGCC). China Southern Power Grid (CSG) is not included neither are various HVDC projects. A variety of converter types and topologies has been used in the process to transmit the large quantities of hydropower available from the North and Midwest to the country’s population centres in the East. Higher voltages (currently up to 1,100 kV) have been used to reduce power losses.

Future development of High Voltages Lines in China

Continuing to build long point-to-point HVDC lines can become a challenge in the future because the power might not be needed in the load centres and flow back through the AC grid to areas between the generation point and the load centres. Connecting these intermediate areas with further point-to-point HVDC could prove to be costly and counterproductive due to the power loop flows and needed AC grid reinforcements.

Figure 12-19: **Map of electricity grid zones on mainland China** [220]



The Chinese grid can greatly benefit by extending these power corridors to connect more cities. This could be achieved by tapping into the existing infrastructures and by changing the planning approach for future lines towards a multi-terminal design. A greater interconnectivity between all provinces would allow more and more distributed generation of RE and thus fulfil growing energy demands. A closer meshing of grid structures would increase the integration of RE that cannot be consumed on-site because they could be transmitted to other areas of the country when needed. This will reduce the strain on the AC network and provide more flexibility. Sector coupling (coupling of different sectors like electricity and heating sector) could help to increase flexibility and stability of the system as well and could help to reach climate goals of the Paris agreement.

13 Creating synergy between carbon pricing and promotion of renewable energy

13.1 Summary

In CREO 2017 the relationship between carbon market and renewable energy development was analysed in relation to the planned introduction of a National Chinese emission trading system (ETS). [221] The report's analysis concluded that in the short-term a Chinese ETS would not influence the coal power price, and thus not provide incentives for promoting renewable energy. The report found that in the medium and long term, a Chinese ETS would have the potential to result in a carbon price sufficient to actually influence the choice between fossil fuel and renewable energy, provided that the design and allocation mechanisms are properly set-up.

CREO 2017 also noted that placing a price on carbon is essential for promoting renewable energy, and a well-functioning carbon ETS should shift the comparative prices of fossil energy and renewable energy. Because China is moving away from direct subsidies for renewable energy such as wind and solar, it is critical that carbon markets are designed to create synergies for renewable energy policy. Carbon markets should be designed with both short-term and long-term energy market impacts in mind. Thus, carbon markets should influence immediate decisions about whether to dispatch renewable energy or fossil energy—such as through their impact on pricing in electricity spot markets—and also to give investors and market participants confidence that carbon prices will reduce the returns on high-carbon investments relative to low-carbon investments such as renewable energy.

Since last year's CREO, the Chinese national pilot for an emission trading system has been set-up for the power sector as a starting point. This chapter begins with an overview of the current status of China's ETS, summarizes the experiences from Europe on the relationship between ETS and RE support policies, and gives an overview of the most recent changes in the policy setting for the European ETS. In general, the European case does not involve direct coordination of renewable supports and targets with carbon markets. Instead, the European experience shows that a stability reserve mechanism, combined with retirement of excess allowances, has the potential to avoid excess allowance situations from developing. The chapter concludes with recommendations for the next step in the further development of the Chinese ETS from a RE promotion policy perspective.

13.2 The Chinese ETS implementation status

Established pilots and supportive polices as foundation of national carbon market

Now the world's second largest economy, China is shifting to a new normal pattern of economic development, emphasizing high-quality growth and sustainability. Economic growth in China will increasingly focus on the service and consumer sectors, as laid out in the 13th Five Year Plan.[222] By placing a price on carbon emissions to reflect the external economic costs of energy-intensive industries, a carbon market can help accelerate China's transition towards a greener, less energy-intensive, higher-quality growth economic model.

To reduce the total carbon emission, facilitate renewable energy development, and explore the operational model of a China National carbon market, China's National Development and Reform Commission (NDRC) launched pilot carbon trading projects in seven provinces and cities including Beijing, Tianjin, Shenzhen, Shanghai, Hubei, Chongqing and Guangdong from 2011 to 2016. In the second half of 2016, Sichuan and Fujian established non-pilot regional carbon trading exchanges. The trading volumes and carbon prices show trends of increases trend since 2013. By May 2018, Guangdong and Hubei achieved the most trading volume: Guangdong traded 73.7 million tonnes of CO_2 worth RMB 1.6 billion, and Hebei traded 55.4 million or RMB 1.1 billion. From September 2017 to September 2018, Guangdong, Hubei, Shenzhen and Shanghai, in these four pilots representing majority of trading volume and value, the carbon prices was traded in the range between RMB 10 and 45/tonne CO_2 equivalent.[223]

Figure 13-1: Accumulated trading volume (left) and trading value (right) of China's regional carbon markets by May 31 2018 [224]

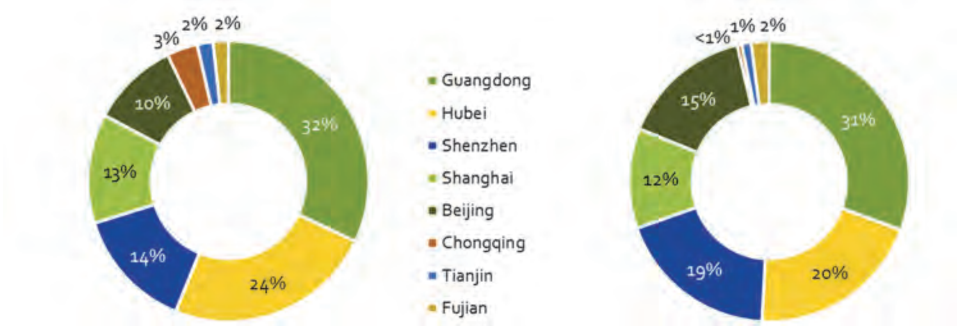
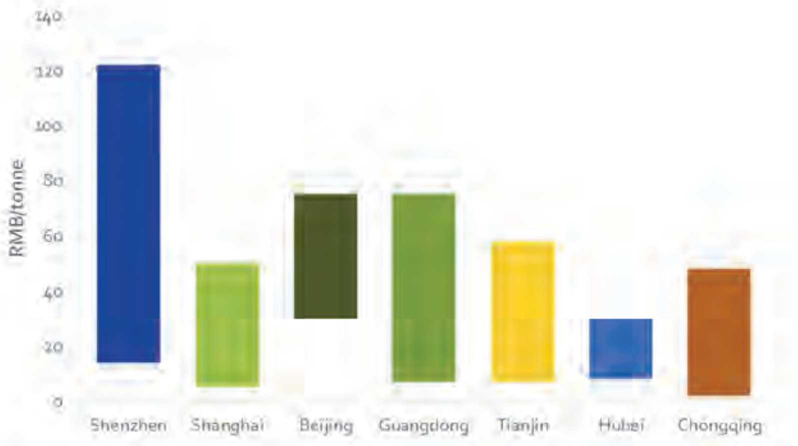


Figure 13-2: Carbon price trend in pilots during 2016/2017 [225]



Apart from the pilot markets projects, the government has also prepared a series of policies for establishing a national ETS. In 2016, the NDRC published a notice on initiating the national carbon market and defined eight targeted emission-intensive industries including petrochemical, chemical, building materials, steel, nonferrous metals, paper, aviation and power industry. [226] The instructions of green financial system co-released by seven ministries and commissions also facilitated the build of a financial supporting system for the ETS.[227] Based on these experiences, the national carbon market was officially initiated in December 2017. [228]

Figure 13-3: Timeline of China's carbon market development

National carbon market to be fully implemented after 2020

According to the NDRC's notice, China's national emission trading system will begin with key emission units in the power generation industry. Key emission units are defined as corporations or other entities emitting over 26,000 tonnes of CO_2 equivalent annually. By this standard, around 1,700 thermal power facilities will be covered by the market as the first round, covering total CO_2 emission of over 3 billion tonnes. The NDRC plans to expand the range of covered emission units gradually, including other high polluting and energy intensive industries as the market matures.

From December 2017, the construction of a carbon market will proceed in three phases. The first phase is infrastructure construction, during which national systems of data reporting, registration and transaction should be completed by 2018. The second is a one-year simulation operation of allowance trading in the power generation industry. The third phase is to deepen and improve the carbon market. Initially, only spot-market allowance trading is permitted, but eventually National China Certified Emission Reductions (CCERs) will be incorporated into the system. Regular trading operations are expected to begin after 2020. Shanghai is responsible for establishing a national unified trading platform, and Hubei is responsible for registration system construction.

National carbon market faces several challenges

In its Nationally Determined Contribution (NDC) submission, China committed to reduce CO_2 intensity of GDP in 2030 compared to 2005 by 60-65% and reach a 20% share of non-fossil primary energy in the energy mix by that time.[229] A national carbon market is one of the most important tools for implementing carbon emissions policies. Compared to administrative policies for emissions control, carbon prices have a greater potential to enable market forces to drive low-carbon investments. In the long run, a national carbon market may enable China to address structural and hidden subsidies provided to fossil fuels, and thereby strengthen the competitive advantages of renewable energy without depending on direct fiscal support for low-carbon technology.

In mid-2018, the Climate Change Department of the Ministry of Ecological Environment (MEE) reported that local governments have fully carried out verification of historical data on local carbon emissions. In addition to submitting the 2016-2017 data as required, they also have initiated the development of emission monitoring plans. [230]

China's national carbon market faces several transition challenges, including establishing management institutions and governmental regulations. After China's the ministerial reform in March 2018, the Ministry of Ecology and Environment (MEE) became the principal ministry in charge of climate change policy in China, and will take over several mandates from the NDRC regarding climate change regulation. Given that many aspects of the future national market remain unknown, industrial stakeholders lack clarity on whether energy-saving and emission-reducing investments made today will result in savings under the future carbon market.

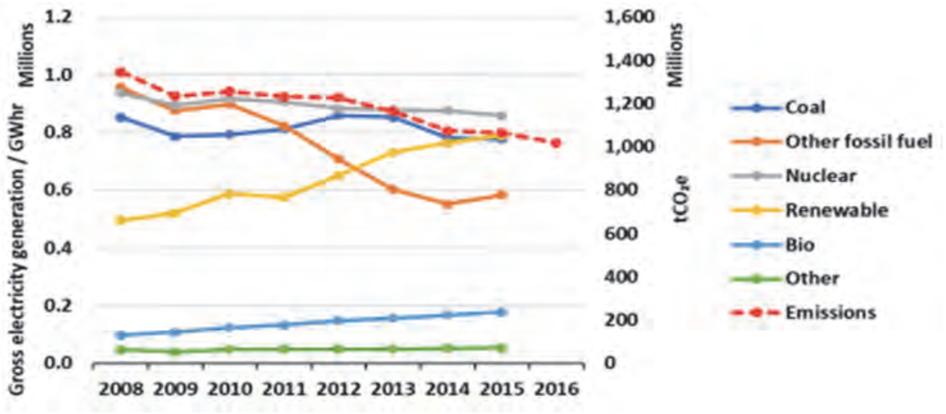
13.3 Prior European experience showed oversupply of allowances

The EU ETS has experienced an allowance surplus since inception, resulting from over-allocation of permits, import of offsets into the scheme, reduced emissions during the global economic crisis of 2008-2009, and advancements in renewable energy and energy efficiency—resulting in emissions lower than policy-makers anticipated. [231] As the data below show, in 2017, EU ETS emissions were at 11% below the cap.[232] Emissions were even lower in 2016, 13% below the ETS cap.[233]

Because the emissions cap was fixed, and countries lacked the political will to adjust the cap—for example, at the beginning of each new phase—the EU ETS resulted in a much lower carbon price level than used in the initial forecasts by the European Commission.

In Europe, low carbon prices in the past have meant that instead of shifting from high-carbon to lower-carbon and less-polluting resources, new renewable energy has mostly displaced gas-fired generation in many EU member states. [234] In turn, renewable investments have mainly resulted from renewable energy policy supports, rather than from carbon prices. As a result, the EU ETS has done little to produce decarbonisation of the power sector in Europe to date.

Figure 13-4: EU28 power generation fuel mix and emissions trends since 2008. Source: Sandbag, State of the EU ETS, 2017



Carbon markets or carbon taxation

In general, there are two explicit options to price carbon; an emission trading system and a carbon tax.

In a carbon market, the government or regulator sets a cap, usually in tons of CO_2-equivalent, on the level of GHG emissions, which can be emitted in a given time period. The regulator issues GHG emissions allowances for every ton of CO_2-equivalent to market participants—which could include all emitters or more commonly a subset of large emitters in selected industries. Market participants are legally obligated to hold enough allowances to cover their emissions, either by buying allowances from others or by holding those originally issued. The allowances have to be bought or they are issued for free to the market participants. The sum of the issued allowances equals the total cap set by regulators. The price of allowances depends on the supply and demand in the market, and requires the allowances have some scarcity value—that is, that market participants expect that allowances issued may be lower than emissions that would otherwise be produced in absence of the cap.

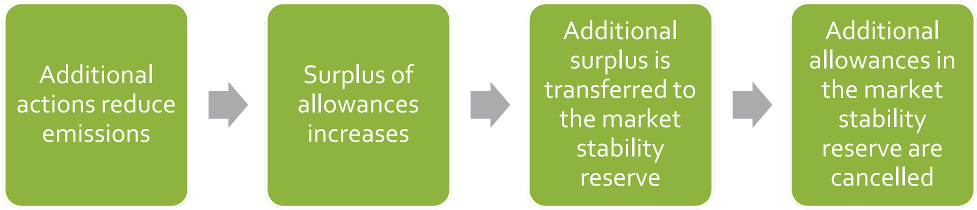
In contrast to a carbon market, a carbon tax is a simple value per ton of CO_2-equivalent which has to be paid by covered emitter for every ton of GHG emitted. Hence, the tax level determines the price of carbon. The main benefit of carbon taxes is simplicity. In many cases, a carbon tax system can be built on existing taxes, and a market-based environment is not required—reducing administrative and compliance costs. If the tax underperforms—reducing emissions less than expected—in theory, policy makers can adjust the tax level. Besides that, a tax provides certainty in respect to the costs faced by emitters. The major drawback of a tax—compared to an emissions trading system—is that a tax does not guarantee that a certain level of emissions reduction is reached.

13.4 The new EU ETS addresses oversupply of allowances

In the first half of 2018, EU negotiators reached agreement on terms of both the EU ETS and the EU Renewable Directive. The ETS was agreed and negotiated first and targets on Renewables and Energy Efficiency agreed only afterwards. Whereas based on prior experience one might expect this order of work could lead to an excess of allowances—due to renewable policy achieving greater emissions reductions than ETS designers anticipated—the EU ETS negotiations have successfully reversed this dynamic by including a self-adjusting mechanism (the Market Stability Reserve, or MSR, introduced in 2014) to correct for oversupply of allowances.

During the final agreement on the future phase of the EU ETS, to start in 2021, a provision of cancellation was introduced, which cancels any surplus over the level of emissions from the year before, as expressed in permits auctioned. This represents a fundamental shift from a fixed cap model to a flexible cap. The more emissions decline—whether as a result of carbon prices, economic factors, coal plant closures, or renewable additions—the more allowances are cancelled from the surplus. As a result, allowances remain scarce, and the market price cannot decline to negligible levels. Given market actors can expect sustained carbon prices, the MSR effectively triggers investment signals and pushes companies and sectors to further decarbonise. [235]

Figure 13-5: The EU Market Stability Reserve mechanism



The market stability reserve simplifies other policy-making

In the EU as in many other regions, targets for renewable energy and other administrative policies are negotiated at the political level. In the case of the most recent negotiation round, renewable and efficiency targets ended up higher (more ambitious) than in initial proposals. This means more allowances will likely end up to be cancelled from the EU ETS Market Stability Reserve and therefore from the cap. In turn, this implies that EU emissions will decline faster than the recently-concluded EU ETS anticipated, but without triggering either a market-distorting collapse in carbon prices or a need to reformulate carbon policies and targets. In other words, because the EU ETS is now self-adjusting, administrative measures and other policies that affect energy markets do not interfere with the normal functioning of the ETS. Market participants can also proceed with investment plans knowing that unforeseen renewable policies or coal plant retirements won't necessarily result in a sudden oversupply of carbon allowances.

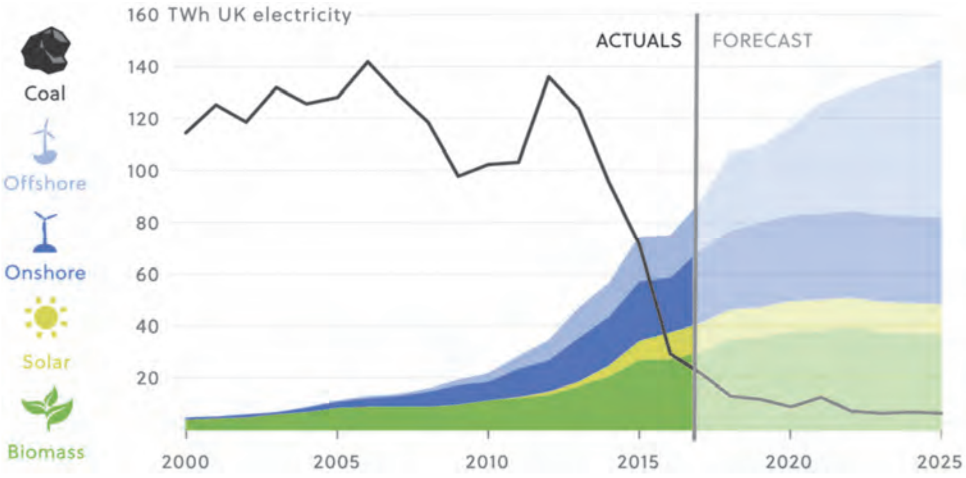
In general, the market stability reserve, along with cancellations of excess allowances, could form the primary mechanism for ensuring that EU renewable policies and carbon markets interact synergistically. In the past, efforts to coordinate renewable targets and carbon caps have fallen short of what was needed to ensure synergy, for several reasons. First, targets are set conservatively, often with political objectives in mind. Second, analysts have tended to make conservative assumptions about the growth and costs of renewable energy, contributing to oversupply of allowances. Third, the value of shifting from administrative to market mechanisms depends on the premise that market participants collectively have better ability to invest and drive cost reductions in low-carbon technology than policy-makers and analysts, who may set targets based on a combination of modelling and stakeholder opinion received through political channels. The market stability reserve described here assumes that officials will continue to face high barriers to perfect coordination of renewable targets and carbon targets. Self-adjustment, in effect, enables the market—the carbon market, and the wider energy market—to cope with high uncertainty around renewable policy.

13.5 Carbon prices can contribute to energy transitions

Given that the Paris Agreement essentially requires the world to reach carbon neutrality by the second half of the century, as well as the rapid decline in cost of low-carbon technologies, the future belongs to renewable energy. [236] Nevertheless, many policy-makers and power industry experts will view 30 years as too short a time to completely overhaul the energy system of an entire country. Yet several cases—such as the U.K., described below—show rapid change is possible, including scale-up of renewable energy as well as shutdown of coal assets.

Now that prices for low-carbon energy sources have fallen—and even become cost-competitive in many regions—even moderate carbon prices can produce real energy shifts. Some policy experts argue that policy-makers will never adopt carbon prices sufficient to signal the need to transition away from coal—or, to put it another way, that energy transitions that depend on carbon prices require politically unrealistic price levels. The case of the UK suggests this need not be the case. Thanks in part to a carbon floor price introduced alongside the EU ETS price, the country is on its way to fully phase-out coal by 2025. Current projections from government plans indicate that by 2025, the 40% of the country's electricity mix previously supplied by coal will be replaced by renewables. This is without any impact on electricity system reliability, and without requiring construction of new gas-fired power plants. While energy efficiency, demand response, and energy storage will all play a role in enabling this transition, the bulk of energy to replace coal will come from renewables.[237]

Figure 13-6: The evolution of carbon factor and generation mix in the UK. Source: Sandbag,2017



The UK example illustrates the possibility of rapid energy transitions

In 2013 the UK instituted its own carbon floor price, which applied as a "top up" to the price to the EU ETS. The government introduced this measure because the EU ETS carbon price was too low to drive carbon-intensive power generation off the market, and therefore was ineffective at either speeding up decarbonisation in UK power markets or guiding long-term investments. Introducing a carbon price floor decreased the economic attractiveness of coal, while also increasing the economic attraction of renewables. Given the prevalence of electricity spot markets in Europe, electricity dispatch is based on lowest-marginal cost principles, meaning that carbon prices raise the spot price of fossil energy relative to lower-carbon energy. The changing position of coal in the electricity merit order has reduced coal's competitiveness compared to lower-carbon fuels, while having little effect on wholesale power prices due to the substitution of other, lower-carbon generation. As a result, by 2025 the electricity output from UK renewable sources will exceed the highest electricity output of UK coal electricity generated in any year this century—142 TWh in 2006.[238] Coal will almost completely disappear from the UK electricity mix. That such a shift can take place in just 10 years, and with only a modest price on carbon, and gives hope that the level of decarbonisation needed globally by 2050 can be achieved.

The UK example is notable for several reasons. The UK was historically the country that kicked-off the industrial revolution by transforming the nature of coal mining, transportation, and industrial production. As in China, many in the UK once viewed coal as synonymous with energy, prosperity, and national development. Whereas UK energy experts once saw coal as an essential baseload power source, today the country often goes for days without any generation from coal power. Second, the UK achieved the most recent phase-out of coal during a period of slow economic growth—when clean energy opponents might have argued against an energy transition on the grounds of waiting for others to act first, or of supporting local coal jobs. Nevertheless, the UK saw a rapid shift towards replacing coal with renewable energy, while mitigating most costs.

Perhaps the most important aspect of the UK case is the interaction between carbon markets and renewable subsidies and policies. The UK has had a variety of renewable support policies over the past decade, including a Renewable Obligation scheme (introduced in 2002) as well as a Contract-for-Difference (CfD) subsidy (introduced in the 2013 Energy Act) for large-scale producers, with prices for the CfD set by auctions.[239] Household solar PV owners receive a feed-in tariff for both self-consumed electricity as well as power sent to the grid, which has encouraged uptake of rooftop solar in the UK since the FIT's introduction in 2010. The household FIT will end in 2019, and starting in 2015 the UK phased out the CfD scheme for onshore wind and solar PV larger than 5 MW.[240] In a recent CfD auction, offshore wind won CfD prices below the prices for new gas or other conventional power plants. Uptake of renewable energy since 2015 has been steady, and the country appears likely to meet its target of 30% renewable electricity by 2020, notwithstanding phase-out of many prior support schemes. The carbon price floor has undoubtedly contributed to the competitiveness of renewable energy in both dispatch as well as for new investments, although it remains to be seen whether a carbon price floor at the present level will continue to encourage new renewable investments without other subsidies.

Carbon prices in the UK have influenced energy choices without imposing high costs. Based on the latest European statistics on electricity prices, the UK household electricity price is close to the average of the electricity price for all household consumers in the EU,[241] despite the UK having a carbon price floor of around Euro 21/tonne, higher than that in most of the EU.

13.6 Carbon prices needed for promotion of renewable energy

As noted previously, the EU ETS has historically faced oversupply, which resulted in low carbon prices. This situation could arise in the future as well, making the price for allowances difficult to predict. In the eventuality of lower-than-foreseen emissions, without an additional adjustment of the cap to reflect a new target, it is likely that the surplus of allowances on the ETS market will grow. With the introduction of the Stability Reserve, along with cancellation of excess allowances, the market now has the potential to avoid the type of price crash seen in earlier periods of oversupply.

A mixture of policies is still needed

Renewable targets in tandem with carbon prices will likely continue in countries across Europe, even as direct support measures such as feed-in tariffs gradually phase out. Other countries, such as the UK and more recently the Netherlands, have been interested in introducing carbon floor prices. Ensuring that the EU ETS adjusts automatically to lower levels of auctioned permits than envisioned, such as through a flexible cap ETS, is another option. As noted above, the existence of multiple policy objectives for carbon and renewable energy, and the need to ensure carbon policy objectives are fully met on both short and long-term time scales, require multiple policies to co-exist.

In regions with active spot power markets and well-integrated power grids, such as Europe and the US, wind and solar power have begun to reach parity or near-parity with wholesale power prices. In some cases, such as in recent peak-power auctions in Arizona (where solar still benefits from tax credits), solar and storage have won technology-neutral tenders pitted against conventional sources of electricity such as natural gas.[242] In Germany, renewable-specific auctions (such as for solar and onshore wind) have resulted in prices substantially lower than former feed-in tariffs, but mostly still above wholesale power prices. In general, the U.S. and Europe continue to rely on renewable-specific policy supports, such as renewable portfolio standards in the U.S. and renewable tenders/auctions in Europe—even in the presence of carbon markets. This is likely due to the factors mentioned above—namely, the presence of multiple policy objectives, and the need for relative policy and market stability to ensure continued growth of renewable capacity. Even in cases of technology-neutral tenders, as represented by Arizona's recent peak power tender, renewable investments typically depend on some form of long-term power contract. As in the case of European renewable auctions, this may still leave renewable investors exposed to fluctuating wholesale electricity prices (and therefore carbon prices). In most cases, renewable policy targets, quotas, or support mechanisms remain in place, at least for the time being.

Carbon prices still needed, and carbon prices more acceptable as RE rises

A recent study published by the Dansk Energi concludes that a high carbon price will be important in continuing to promote renewable energy. In the absence of a moderate carbon price (Euro 31/tonne), the share of renewables in the power system that the market could reach on its own, without support, in Northwest Europe would decline by 5% relative to a base case, and by 8% when compared to a higher level of Euro 62/tonne.[243] Given the existence of spot markets and large proportions of low-marginal-cost wind and solar bidding into the market, the merit-order effect means that carbon prices are having less effect on average electricity prices due to renewable energy participation in the market. This implies that the long-term emission factor of price setting technologies is decreasing as more renewable energy enters the market, reducing the impact of carbon prices on consumers. With a switch from coal to renewables within the electricity sector, this effect is likely to become even stronger, making higher carbon prices more palatable to market participants and policy-makers alike. At the same time, inclusion of sectors such as heating and transport into carbon markets will also broaden the impact of carbon prices, enabling a wider variety of technologies to participate and benefit from low-carbon investment shifts resulting from carbon markets.

Renewable support policies and other policies exist side-by-side with carbon prices

China, Europe, and many other regions supports renewable energy with separate policy measures such as quotas, targets, tax subsidies, and feed-in tariffs. Some proponents of economic theory may argue that carbon prices and other environmental taxes or usage fees render renewable support policies unnecessary. According to this reasoning, an efficient carbon price would lead market participants to invest in research and development and ultimately scale-up of technologies needed to reach environmental policy targets. Evidence from the past two decades of experience in Europe, the U.S. and China suggests that governments adopt renewable support policies for a variety of reasons, and that such policies are highly effective in their own right at promoting technology innovation as well as commercial deployment of clean energy.

Published research has generally found that carbon markets have played little role in development of renewable energy and carbon prices have been too low to stimulate renewable energy deployment. Low prices and long-term price uncertainty have meant that carbon pricing has stimulated small-scale investments with short-term payback periods but does very little for large-scale investments with longer payback periods.[244]

Renewable energy has typically required special policy supports—especially in its early phases of development. First, the long-time horizon and uncertainty of technology investment—even for technologies already commercially available—hinders investment in new industries. Second, the energy industry is dominated by large, capital-intensive companies, often under regulated monopoly structures, which earn economic rents by owning or operating existing assets, and these players are reluctant to invest in new technologies that might create unwelcome competition or undermine existing asset values. Third, large knowledge spillover effects imply that early adopters of a given technology must take high risk to enter a promising field, but nevertheless may not benefit when a technology becomes widely available and costs fall. The rapid learning curve seen in both manufacturing and deployment of solar PV illustrates the benefits of policies aimed at scaling up emerging clean energy technology.

Having multiple policy objectives is another reason for multiple policy instruments. The Tinbergen rule—named for the Dutch economist Jan Tinbergen—states that the number of policy objectives should equal the number of policy instruments for an efficient outcome. An ETS is designed primarily around a carbon policy objective. While renewable support policies also relate to decreasing GHG emissions, they also serve goals such as diversification of the energy mix for greater energy security, reducing fuel imports, supporting local industry, and reducing renewable manufacturing costs by promoting rapid scale-up and deployment. As the IEA notes, "Layering of policy incentives to ensure achievement of a certain target [can] justify multiple policies in a situation where constraints do not permit a single policy. Policy co-existence can be justified if policies are aimed at different specific outcomes within an overall strategy... For instance, one policy can be set to achieve short-term environmental targets and another policy for longer term targets."[245]

13.7 Recommendations for China

Carbon and renewable policies will continue to co-exist, even as feed-in tariffs phase out.

The rapid decarbonization of the power sector as stipulated by the Paris Agreement implies the need for concerted efforts to both adopt pricing for carbon to incentivize cleaner energy development as well as maintain some supports for renewable energy. While many countries are in the process of transitioning away from traditional feed-in tariffs for large-scale wind and solar, the need for investment certainty to enable continued investment in renewables—even where price parity with wholesale power prices is close or already achieved—implies the need for ongoing policy supports such as quotas or tenders/auctions. (For greater detail on such supports, see the Renewable Incentives chapter of this report.)

Carbon policy should contribute to shifting away from coal and towards renewable energy.

To date, carbon markets in the U.S. and Europe have played little role in promoting renewable energy relative to other policy supports, but this is now gradually changing as the need to decarbonize the power sector has become more widely recognized. To ensure carbon markets help renewable energy, and avoid investment lock-in of high-carbon power generation, carbon markets in the power sector should apply to the entire power sector. Carbon markets that merely help optimise dispatch of thermal generation, or incentivize investment in newer coal capacity—such as might take place if the China carbon market is based on full and free allocation of allowances to existing and new coal plants, with no impact on final prices—are no longer sufficient, given the urgency of creating incentives for transitioning away from coal and towards renewable energy. In markets where dispatch is based on lowest marginal cost, carbon prices can contribute to the transition towards renewable energy both by raising wholesale prices for conventional energy sources relative to renewable energy. Carbon prices can also enable revenue from sale or allocation of allowances to be allocated for renewable energy deployment, low-carbon technology research & development, or other energy-transition related costs.

A carbon market should 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 likelihood of oversupply, and divergence from business-as-usual scenarios creates a bigger need for a well-designed price stability mechanism. A strategic market reserve might be insufficient if a large volume of allowances needs to be removed from the market. If market actors believed allowances in the reserve would at some point flow back into the market, this would have the effect of suppressing prices for a longer period of time, and limit the incentives for long-term investments in emissions reductions. A stability mechanism with price floors and ceilings may be a more suitable mechanism for a country where processes such as economic growth and technological cost developments are harder to predict. An alternative used in the EU is the permanent retirement of excess allowances in the MSR after 2023. Furthermore, carbon targets and goals require periodic adjustment to ensure incentives remain aligned with environmental and economic policy goals—but too-frequent adjustment creates market uncertainty and risks hindering investment. Rebasing carbon targets every five years, or on a moving-five-year average, would be compatible with Paris Agreement goals.[246]

As China plans to introduce national carbon pricing through a carbon-market, the most important element is for the cap to contain a build-in mechanism that allows policy-makers to ratchet it downwards after large drops in emissions resulting from coal closures and renewable roll-out required to meet the objectives of the Paris Agreement.

14 Interaction between heating and power sector

14.1 Summary

Both China and Denmark have long used waste heat for heating, and both countries today seek to enhance the efficiency of heating systems to achieve climate and energy efficiency goals. This chapter draws on lessons from Denmark's heating system and makes recommendations based on China's present situation.

District heating systems have the advantage compared to individual heating systems that it can collect waste heat from electricity production, industrial production, cooling, and waste incineration. District heating can collect low temperature renewable energy from the ground or from other sources like wastewater plants. District heating can use many different sources at the same time and can store energy in large storage tanks. Because of these characteristics, Denmark has established district heating in all areas with high building density. District heating is no longer a result of available waste heat but rather a planned system independent of the availability of waste energy. Denmark's Heat Supply Act regulates the heat planning process to make sure solutions adopted are both economically viable for heat users but also economically viable for society as a whole.

Given its situation with many large, dense cities, and high variety in potential waste heat providers and customers, China may opt for a regulated heat planning approach including environmental and climate benefits of heat planning. For rural areas, where unabated coal heating is still common, heat pumps and solar heating may offer the best solution. For cities, including small- and medium-sized cities, district heating may be the best option. Currently, waste heat from many power and industrial processes is wasted in cooling towers. While China has plans to expand combined heat-and-power, China has the opportunity to go beyond CHP and create integrated markets for heating and power. In particular, we suggest:

- Variable wholesale and retail prices for both heating and power are necessary to prevent market failures, such as curtailment of renewable energy in winter. With market incentives, district heating can become an efficient heat "battery" to store heat for when it is needed.
- In cold and severe cold areas and even in temperate areas district heating supply should be measured and delivered for both heating and hot tap water supply all year.
- In areas with hot summers and cold winters and even in areas with hot summers large buildings should be equipped with ventilation systems, which can be heated in winter via district heating and cooled in summer with absorption heat pumps supplied with heat from district heating.
- Ensure energy and environmental taxes are applied efficiently at the level of units of emissions and fuel, to prevent double-counting of environmental attributes and effective price signals of external costs to users of heat and power.

14.2 Introduction

China and Denmark each have targets for creating efficient energy systems for reduction of climate effects, for reduced dependency on imported fuel, and for lower environmental impacts from energy use. One of the main tools for efficient energy systems is district heating in areas with cold winters using waste heat from power production, to use the same energy resource for both power and heat, thereby saving fuel used by individual heating boilers. China and Denmark have both employed district heating for many years, and the expansion of the district heating network has primarily been a result of the available waste heat from CHP plants.

In recent decades, Denmark's approach to district heating has evolved, and we expect district heating in China to undergo a similar evolution. At an early stage, Denmark recognised that the best way to reduce dependence on imported oil and coal was to reduce energy consumption and to find local energy resources. Subsequently, adoption of climate change targets this approach even more important. As a result, Denmark developed a domestic natural gas system based on domestic natural gas resources; wind power; CHP from coal, natural gas, bioenergy and waste; solar PV; and recently biogas expansion and supply to natural gas grid. For Denmark to achieve independence from fuel imports become a low emission society necessitated the very high overall efficiency and flexibility advantage of district heating.

The expansion of electricity production from renewable wind and solar adds an extra perspective to district heating systems, which are the second most flexible energy storage after hydropower for balancing fluctuating power production. The combination of CHP plants, electrical boilers, and heat pumps combined with heat storage systems can deliver the needed flexibility. This means that Denmark can integrate gas, power, and district heating sectors, to cope with increasing variable power supply on the road to a fossil free society in 2050.

China also has ambitious targets for renewable energy expansion, but presently, despite having a lower share of variable renewable supply compared to Denmark, some areas suffer high wind and solar curtailment rates. Danish experiences can inform solutions for China, and this section introduces tree main approaches, interactions between heat and power sector, heat planning and market design to bring the energy sectors closer to each other, and how to increase the interaction between heating and power systems.

14.3 Interactions between heat and power sector

The power system

When the power system is based on dispatchable thermal- and hydro power production, power production can be aligned with the electricity demand. In future electricity systems, variable production cannot follow the power demand and is wasted if curtailed. Achieving the maximum benefit from the renewables requires the power system to absorb or store variable power when in surplus and inject it into the grid at times of relative short supplies. This can be achieved in several ways, but ideally the solution should include incentives, otherwise the investments and costs for storing and releasing cannot be recovered. In the following some of the necessary changes in power system are discussed in relation to the benefits that can be gained when power and heating sector is integrated better.

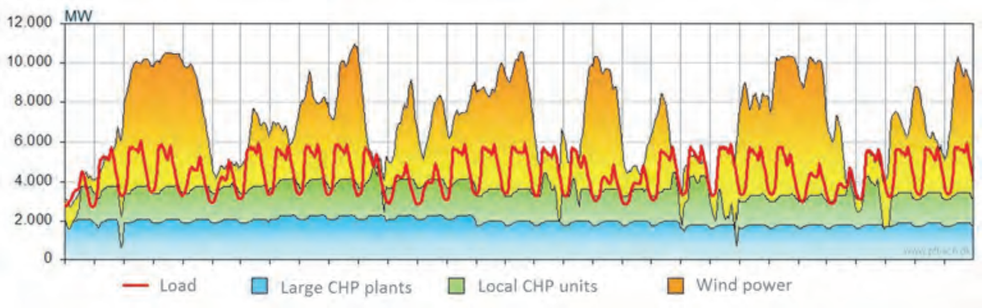
Market price

In China the power price is set administratively and does not fluctuate according to the actual demand and supply situation. Combined with contracts based on minimum and guaranteed annual thermal power production hours and the need for heat production in winter time, this can lead to curtailment in areas with fluctuating power production. The obvious solution is to implement power market platforms, which will give heat sector incentives to produce and use power when optimal for heat prices.

Grid connections

Even with a market platform, the problem with curtailment can occur in winter periods in areas with high share of CHP plants, which have to deliver heat. Figure 14-1 shows an example of this problem from Denmark in a winter month.

Figure 14-1: Example one-month demand and supply in Denmark [247]



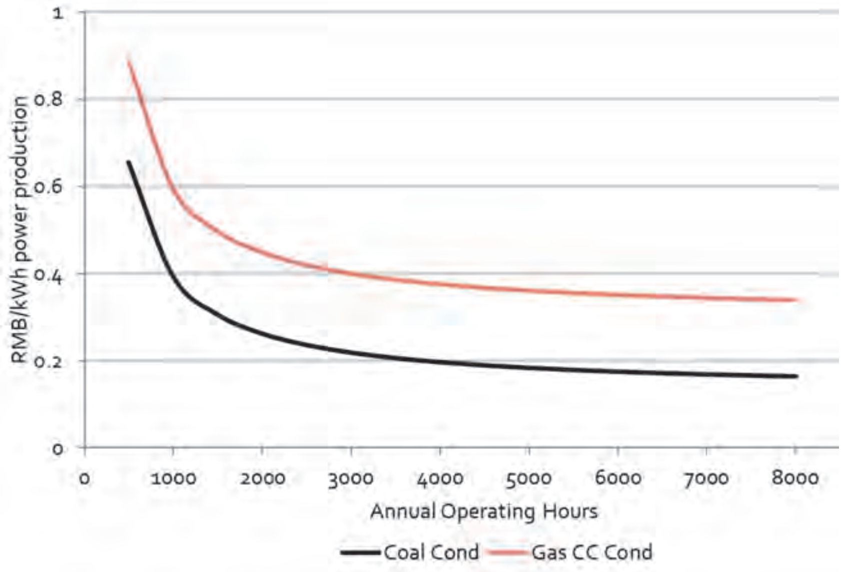
Large and local CHP plants operate to meet heating demand and are only in small scale reducing the power production in nights and weekends due to storage tanks in district heating systems. The huge power production compared to demand is a problem in Denmark, which the country resolves primarily by exporting electricity to countries north of Denmark with hydro power systems able to hold back their own power production. Denmark has power transmission capacity larger than peak demand—by around 6,500 MW—and new connections are planned and under construction. The extreme export in periods with abundant wind causes low power prices; Denmark has the second lowest prices in Europe next to Norway, which imports most of Danish surplus electricity. Norway, in turn, exports this electricity back to Demark in periods with low wind production, leading to lower Danish power prices in both good and poor wind conditions, which makes it difficult for local natural gas-based CHP plants to compete on the electricity market. The heating system tends to find other heat sources like biomass or natural gas boilers which do not feature integration between heat and power.

Using hydropower as a battery for absorbing variable renewable output is the best solution, but often hydro plants are not located near variable renewable resources. The distances from large demand centres such as cities, wind and hydro power stations are often too great, and thus too expensive. In this case, other solutions have to be found.

Flexible power or CHP plants

With increasing variable renewable output the most obvious solution is to decrease production in thermal power plants. This can create stranded assets in the power plants; alternatively such plants may require higher electricity prices to compensate for fewer operating hours. Figure 14-2 shows an example of two types of power production units.

Figure 14-2: Production costs as function of running hours in power plants including investments costs. China fuel price and costs from LCOE calculator DEA 2016



The power price includes investments costs and is a function of annual operating hours. For example, if a coal fired power plant reduces the annual running time from 5000 annual hours to 2000 hours, the average electricity price for sold electricity needs to increase from RMB 184 /MWh to RMB 263 /MWh to cover the costs. The power marked has to deliver higher price when the operating hours are falling; otherwise the plant may be forced to close.

The figure also shows that coal power are cheaper than combined cycle gas turbine plants when investments are included due to coal price of RMB 17 /GJ and natural gas price of RMB 48 /GJ.

Relative to CHP, power-only plants are inefficient; in the future, CHP plants both producing heat and electricity will be the primary power producing units. Bioenergy CHP pants are not included in the figure due to same investments costs as coal and higher fuel prices. Bioenergy CHP remains uncompetitive without subsidies at the current fuel prices.

If the power market is unable to support a higher price for the electricity due to cheaper variable renewable production solutions, the only way the power plant can be compensated is to change to CHP production, to obtain additional revenue from selling heat to customers, compensating for lower operating hours.

Flexible demand

Using surplus wind and solar output for heat storage can help eliminate curtailment, even with higher shares of variable renewables. Figure 14-1 shows periods with fluctuating power production of 6000 MW and at same time power demand between 4000 and 6000 MW. Even curtailing hydropower, thermal power or/and CHP power production may not be enough to solve the problem. In this scenario, some kind of "battery system" is needed. An obvious solution is to use the district heating systems as a battery: the CHP plant stops power production when prices are low and instead uses the same cable for electricity consumption in an electrical boiler or heat pump. This is the present development in Denmark, but the incentives have until now been too weak compared to building transmission.

Another solution is to increase demand by replacing fuel consuming equipment with power consuming equipment. This will only increase flexibility if both the fuel consuming and the power consuming equipment can be simultaneously switched on and off, otherwise this will only constitute an additional electricity use. This solution can only absorb electricity and cannot return electricity unless the installation has CHP capacity, and then it is the same solution as CHP plants with electrical boilers. In Sweden, for over 20 years industries that use steam and heat have employed this solution via electrical boilers in CHP plants, as a way to integrate abundant hydro output.

As this section has shown, district heating systems can be a central solution for balancing power systems. The next section discusses how heat planning can make this happen.

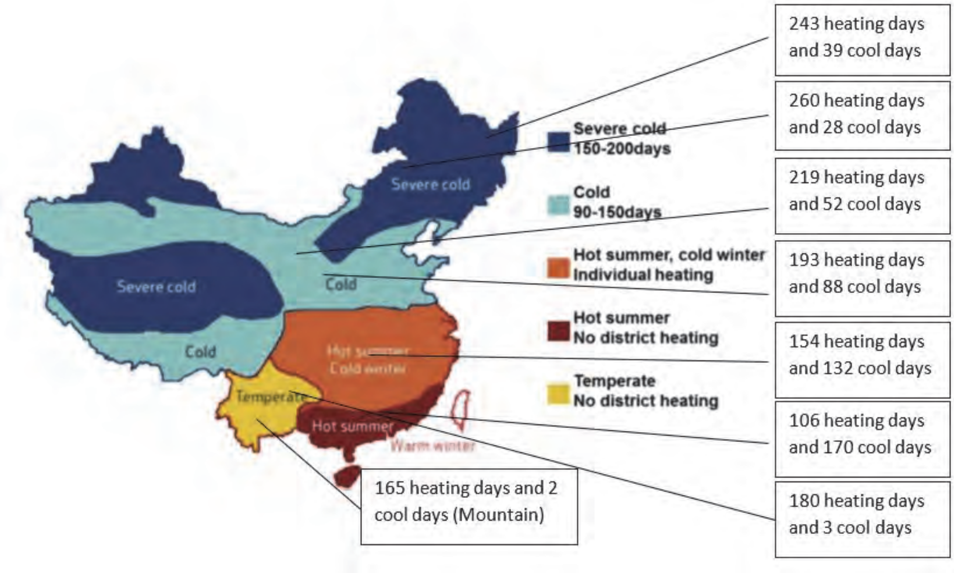
14.4 Heat planning

Introduction to district heating in China

In general, district heating transports energy from a source to users. District heating is not an energy form or a fuel in its own right, but rather supplies hot water or steam and returns cooled water after the heat has been removed. District heating can also be reversed to supply cold water for cooling, and then receive the heated water—as in district cooling systems.

Building heating or cooling demand depends on the outside temperature. Normally the average daily temperature determines heating demand, which begins when average outside temperatures drop below between 16–19 °C. Heating demand for a specific building depends on building insulation, other heat sources inside buildings (lighting, computers, monitors/televisions, and any other electrical devices that give off heat), occupancy, and user needs related to comfort. In some countries with high income the average heat set point in buildings are higher than the set point in other low income countries. Some climate zones occasionally see heating demand in summer due to low average temperatures; in many climate zones there is no heat demand at all in the three to five summer months. In some countries, including Denmark, district heating supplies domestic hot water as well as heat for space heating in summer creating a summer base-load level. This is not the case in China.

Figure 14-3: Heating zones in mainland China[248]



In figure 14-3, displaying the climate zones in China, the boxes show the length of the heating season for a number of cities representatives of different Chinese climate zones (Harbin, Xilin-Abagnar, Yinchuan, Xi'an, Wuhan, Shauóguan, Quijing and Kunming). The difference in heating days compared to the original source is due to using a different definition of heating days. The heating days in the boxes are defined as the number of days with average temperatures below 16 °C and cooling days are defined as the number of days with average temperatures above 23 °C.

Severe cold and cold areas include fifteen Northern provinces and occupy more than 70% of the area in mainland China. In the long-term, when 4th generation low-temperature district heating systems become standard, district de-centralised heating systems on basis of renewable sources like solar heating, geothermal heating and air- to-water heating might be favourable to establish in this area. Even in temperate areas and areas with hot summers and cold winters district heating can be favourable due to many heating days.

District heating systems in China has traditionally been concentrated in towns north of the Yangzi River and based on available waste heat from power production and in a few cases on industrial surplus heat from steel plants. In large Chinese cities with many multi-storey buildings and lacking nearby power production, heat supplies are commonly based on coal or natural gas boilers delivering heat for several buildings through a local distribution system. These boilers often have high pollution emissions, are inefficient, and are normally only used four to five months in heating season. The remaining heating in China are based on individual boilers using various fuels and electricity.

A central challenge for renewable integration in China is that that many CHP plants continue producing both heat and electricity due to heat demand, even when there is a need to curtail electricity production to absorb abundant local wind or solar power output. There are normally no heating alternatives in form of reserve heat production units or heat storage systems. Chinese CHP plants in these district heat systems increases the need to curtail electricity production in China in the heating season due to power production. This is a key issue that China needs to address in the heat planning.

The need for heat system planning

District heating systems have an advantage compared to individual heating systems in that it can receive waste heat from power production and surplus energy from industrial production. District heating can also use waste heat from cooling and from waste incineration. It can collect low-temperature renewable energy from the ground or from other sources like wastewater plants. In other words, district heating can efficiently gather and transport low-value energy from many sources to heat consumers.

District heating can also store heating energy in large storage tanks. Analysis of the losses in production and transportation of district heating generally shows that district heating offers higher efficiency than individual solutions, as well as higher flexibility critical to integrating other energy systems such as renewable electricity production.

In figure 14-4 it can be seen, that DH uses less fuel, even when taking into account heat losses in DH production and transportation. Pure renewable heating sources like geothermal and solar heating, which consume no fuel other than electricity, can provide high efficiency inputs to district heating systems.

Figure 14-4: Fuel efficiency (Input fuel MWH /Output heat MWH %). Technologies from Danish Technology catalogue.

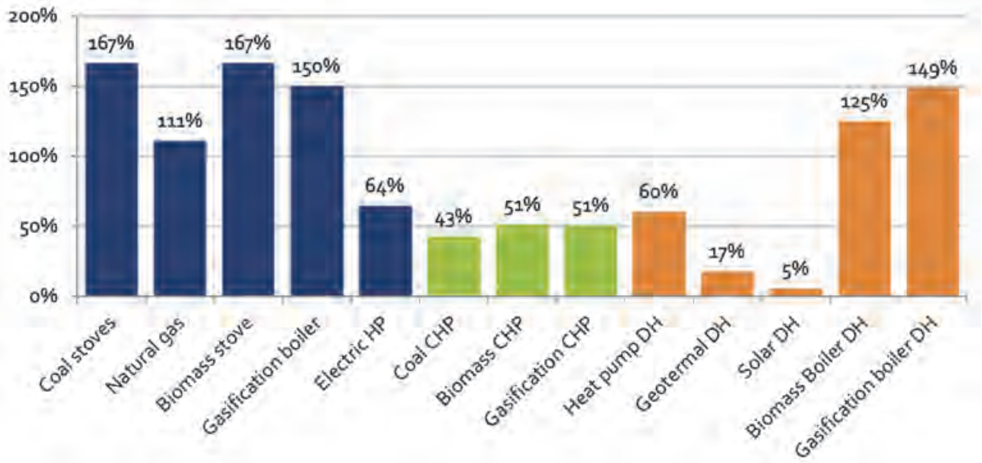


Figure 14-4 shows that in general district heating solutions consume less fuels than individual heat supply solutions. The main reason is that cogeneration shares the fuel between heat and power production. It also shows that large plants can be more efficient than individual plants. District heating is normally cheaper due to high efficiency and lower peak capacity per consumer. Heat pumps are better in district heating systems due their higher overall efficiency. Heat pumps can also add flexibility to the power system by cycling off when power supply is in shortage and thermal plants are operating; this further improves the efficiency performance of heat pumps in district heating systems beyond what is shown in the figure.

To become independent of imported fossil energy and fulfil Danish climate targets, it was necessary to establish district heating in all areas with high building density. District heating is thus no longer a result of available waste heat, but rather represents a planned system independent of the availability of waste energy. This necessitated Denmark to change its energy planning approach and carefully plan where to build district heating.

When planners identified an area as appropriate for district heating, they next identify suitable and efficient heat sources. Often, there are several heat sources, and planners next optimise the scale of each category and production unit of heat sources in terms of both low production cost and high efficiency. Planners will consider efficient baseload CHP heat production facilities, waste incineration baseload, heat pump baseload, or bioenergy baseload, combined with less efficient but by lower investment cost reserve and peak load production facilities.

Some of the technologies, such as heat storage tanks, are not baseload from a heat point of view, but rather absorb heat from power production when power peak load is needed or heat from electrical boilers when power production is very high. CHP units can be peak load units in some cases, especially when they cannot compete on marginal production price and the operating hours decrease. The main economic incentive for investing in electrical boilers and CHP power peak load must come from the power system, or district heating companies will not invest in or continue to operate such facilities. The power market price system is important for this integration of heat and power systems, but tariffs and taxes can also play a role in determining investments.

When heat planning yields multiple heat sources, the heating system may end up with a very high total heat supply capacity. The plants will often be able to deliver 2-3 times the needed capacity if all units were running. From a cost perspective this overcapacity can be a problem, leading to high depreciation costs and hence high heat prices. This can be addressed by investing in long lifetime equipment financed by longer-term debt.

Heat planning is essential for Denmark to reach its targets for efficiency, climate, and fossil fuel import independence. Denmark's Heat Supply Act regulates the heat planning process to sure the decided solutions that are both economically viable for heat users and also economically viable for society as a whole. The best solution requires consideration of societal costs for the expected pollution compared to pollution from existing heating sources. Including external costs from pollution in the calculation normally makes renewable energy sources and efficient solutions more competitive.

For China, a regulated heat planning approach that includes environmental impacts and climate effects can help establish an effective, balanced, and flexible heat and power sector. This would contribute to achieving China's energy, environmental and climate targets, particularly in heating regions.

The ideal interaction between heating and power section: heat planning

As noted previous, CHP production combined with reserve heating capacity, electrical boilers, heat pumps and heat storage systems in district heating systems at the same time can provide very high energy efficiency and flexibility to the power system. Heat-based storage solutions at the same time can create high efficiency in heating sector and the overall energy system will be smarter, probably cheaper and less polluting compared to other solutions. Integration between power and heat sector is optimal in most cases. This discussion focus on how to design an efficient, integrated heat and power sector in China.

The present district heating system in China delivers increased efficiency through conversion of power plants to CHP plants, but in some regions this decreases the overall efficiency of the energy system due to curtailment of variable renewable energy such as wind and solar. In some regions, local power overcapacity means the heating sector cannot be expanded further, at least under China's present heat planning approach. In our view, this view of district heating and the planning of district heating systems in China should be adjusted to in favour of overall optimized efficiency and flexibility. Power and heat face four general situations, and each requires a different solution:

1. Local inefficient and polluting heat systems
2. Waste sent to landfills instead of employed in waste-to-energy systems
3. Power plants do not use waste heat
4. Regional CHP capacity exceeds local power demand

Local inefficient and polluting heat systems

Many Chinese towns and rural areas are heated by inefficient stoves and boilers using coal, locally-available biofuels, or natural gas—often without any kind of pollution emissions abatement. The efficiency of the equipment is often poor, leading to high fuel consumption. There is a need for change.

For rural areas and small towns with low building density, electric heat pumps combined with solar panels for hot tap water in summer typically offer the best solution. The heat source can be the air, but also geothermal heat from small boreholes or underground pipes. To achieve high efficiency and to save investments in heat production capacity, improved building insulation is almost a must in these areas. Small bioenergy boilers often have the same particle pollution problem as coal boilers and do not seems to be the best solution in these rural areas. High efficiency natural gas, biogas, or gasification condensing boilers can be the second best solution, but gas resources may be limited and better used in CHP plants or by industry. The electricity used for the heating can be provided from wind power, and from CHP plants in towns with high building density.

In areas with many cooling days, the same heat pumps can be used for cooling and the electricity use in summer can be powered by local solar PV in daytime, where the demand for cooling is highest.

In small, medium, large, and very large urban areas with high building density, the future and best heat solution may follow the approach described in the next three sections.

Waste sent to landfills

Waste contains both organic materials and plastic resources suitable for energy purposes. Compared to the benefits for environment, energy utilisation from waste seems to be a better solution than landfilling saving emission from the landfilling and from the fuel it replaces. Waste should first be sorted and the fractions with positive value recycled, but there will always be a remainder that is cannot be reused or recycled, and this should be used as an energy source. Incineration of waste or conversion to biogas are possible solutions, and the choice depends on the waste composition. Incineration in boilers or CHP plants depends on the electricity situation in the area. In either case, some residual heat from waste-to-energy processes be used for heating or cooling of buildings. In Denmark, municipal waste and waste from industry covers almost 25% of the district heating demand. Waste-to-energy plants can become a baseload supply for heating, cooling, and perhaps power in all large urban areas of China.

In Denmark and other European countries where waste plays an important role the incentive for energy, power prices and heating prices are insufficient to incentivize high waste utilisation for heat. Instead, the incentive to use waste for energy is results from high taxes on landfilling, which in turn makes it possible for waste-to-energy plants to offer competitive power and heat prices. The tax systems, fines, and other fees also create powerful incentives to preventing unauthorized dumping of waste in nature, and these also have to be balanced with incentives for sorting to prevent incineration of valuable resources.

Power plants not using heat

In Chinese urban areas with high building density an obvious choice will be excess heat from power plants. If there is a nearby power plant the town should be converted to district heating and the plant converted to CHP. If the power supply system needs more thermal electricity capacity new CHP plants should be built nearby towns with high building density and not larger than the heat supply can be covered by up to 80% of the heat from CHP plant. Danish experiences shows that building plants producing more than 80% of peak heat demand results in excessive investment cost compared to building peak heat load boilers that also can be used as reserve heating plants. If more thermal power capacity is needed for peak heating load, the best option is often to add heating capacity in another town with heat demand. Bioenergy or waste incineration CHP should be considered solutions if fuel resources are available and economic incentives sufficient.

In China it is still uncommon to use the waste heat from power plants to produce heat for domestic hot water and space heating in summer. Instead most power plants employ cooling towers to shed heat from power production, and cooling towers in turn consume electricity. District heating networks can provide the same cooling as cooling towers. If the district heating company gets paid for tap water, supplying heat in summer seems to be the best choice in cold and severe cold climate zones, as shown in figure 14-3. Even in temperate climate zones, district heating systems could benefit from selling heat in summer. It is though necessary to measure the heat consumption and to establish payment systems according to the energy consumption.

In areas with hot summers and cold winters and even in areas with hot summers, large buildings should be equipped with ventilation systems that can be heated in winter directly from CHP plants via the district heating system, and cooled in summer with absorption heat pumps supplied with heat from the CHP district heating system. The overall efficiency may be very high in areas with cold winters and hot summers, if most large buildings employ this kind of district heating system for both heating and cooling. Absorption heat pumps may be uneconomic in small buildings, where electrical heat pumps may be a better solution.

If a thermal power plant cannot find a nearby use of the heat, this implies the plant was built in the wrong place, and should be the first to operate less when electric curtailment is needed.

The overall CHP capacity exceed the power demand

When the power capacity in thermal CHP plants exceeds the power demand in many hours, the plant has to be more flexible. This can be achieved by building storage tanks for storing the heat produced in periods with power demand to periods without power demand. Expanding the district heating supply system must be based on other heat sources than CHP. If the heat supply capacity is limited the CHP plant can bypass steam and produce 100% heat in periods with no power demand—or even better, install an electric boiler producing heat from the minimum produced power by the turbine in periods with high heat demand. Solutions with electric boilers create larger flexibility for the electricity system and will give the CHP plant possibilities regarding frequency regulation and short-term reserve power capacity. Using an electric boiler in CHP plants provides double the flexibility due to both shutting power production down and starting up use of electricity. The restriction is demand for the produced heat, and here storage tanks and 4th generation district heating system with low heat losses can be important.

A part of the solution with too high CHP capacity is to install heat pumps in rural areas and heat pumps in towns without CHP capacity available eventually using low temperature surplus heat or other heat sources. Converting fuel based solutions to power based solutions will create higher demand for power and increase the demand for CHP capacity.

When the heat capacity in CHP plant is too high compared to heat demand the district heating system could be expanded to supply additional areas.

14.5 Market design

When heat and power sector are integrated incentives for both heat and power production has to be aligned with each other. If for example the incentive for power production caused by high fixed power price or high subsidising the companies will build CHP plants with high power efficiency not concerning about heat efficiency. The electricity prices will pay all the costs for the low efficient heat and give the primary revenue. If the heat efficiency gets to good the revenues from power sale will fall due to falling power production caused by the efficient heat production. The company is not interested in efficient heat production and the society gets an inefficient system. Another example can be the tariffs or tax on use of electricity. If the tariff and/or the tax paid per kWh are set high there will be little incentives for using electrical boilers or heat pumps in heat system and an optimal interaction between power and heat side will not occur. These examples shows that fixed prices, tariffs and tax can result in distorted incentives and cause cross-subsidisation between sectors. In next sections this will be discussed.

Price systems for fuels and power

As noted above, a market price system for power, fuel, and heat gives the right incentives for integrating power and heat sector. Market price systems will induce power producers to optimise power output for highest revenue. It will also induce heat producer to optimise heat output, particularly if this requires optimising between electricity as a fuel input versus other heat energy inputs. Both the power producer and heat producer will use the incentive for stopping production if there is an oversupply of heat or power, and there will be incentive for both heat storage and electricity-based heat production in boilers or heat pumps.

When producing both heat and power in a CHP plant, under a market-based system it will sometimes be the power price and other times the heat price that 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 that the electricity price is too low for electricity production but the heat price high enough to produce CHP even if the heat side have to pay for the loss on the power side. In principle, power production should stop and the plant should continue producing only heat through by-passing of the steam for the power turbine, or through using the produced power in an electric boiler. Without such flexibility, the heat side will cross-subsidise the power side, and this causes a market failure in power market leading to excessively low power prices and potentially curtailment of other, more economical power supplies.

The reverse situation can also occur, in which the heating price is to low compared to alternative heating sources and the power price high. By producing both heat and power, the power side will subsidy the heating side and result in a market failure in the heating market. The two examples in practice show that the split of costs between power and heat should be variable and depend 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 only creates problems in the heating market, and does not lead to wind and solar curtailment; heat storage systems can resolve the problem by storing heat for periods with higher 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 allowing individual participants controlling the market and market pricing.

Tariff system

The payment for transport of energy is normally included in energy price in non-market energy systems like the Chinese for both power and heat. It is paid in the same units as energy and the costs are not transparent. In the power system this would be in RMB/kWh and in the heat system in RMB/m^2 heated floor area. When a market platform is established, the transportation costs and payment can be included as a part of the market system or it can be a payment system running beside the market system.

When the market system is based on a hub, or the geographic centre of producing and consuming activities, then all selling parties will have to pay for the transportation to the hub and all the buying parties have to pay for the transportation from hub to the consumption site. If the transportation can be shortened or if somebody has sold the same transport capacity in the reverse direction, the selling, the buying, and/or the transportation company can save money. The transportation can be traded beside the normal market on other market platforms like swap markets. The positive aspect of these other markets is that the transportation costs at the end will look like real costs for transportation from producer to customers, while the transport network utilization is optimised. This kind of market is common for trading fuels or other goods that can be transported in specified units or where there are real or defined hubs like oil and gas markets.

In electricity and heat markets it is difficult to identify a single centre of activity. There will often be several producers and consumers in a network, where both the producers and the consumer have limited ability to discover the cheapest transportation path. In this kind of market, the company taking the energy out of the system pays the producer for injecting the same energy value into the network at the exact same time. Bottlenecks define pricing zones. If a connection between two areas cannot deliver enough capacity compared to supply or demand, there will be a price difference between the two areas, but inside the area the price for energy will be the same. It is difficult to include transport costs in this kind of market platform the same way as for hubs, but possible to swap production or consumption between the areas if energy is sold in both directions.

It is difficult to set the ideal payment for heat transport costs in this kind of market, and the operators often set a price in same unit as payment for the energy. In electricity system this payment often is in RMB/kWh and in heat sector in RMB/m^2 heated floor area, or in

RMB/kWh measured and delivered heat. In both systems it is also common to make consumers pay all transportation costs and hold producers free or almost free of payment. That is fine in closed systems, but hinders competition when energy is exported from the system without transport payments. Providers of flexibility in the system paying for transportation cannot compete with export customers not paying for transportation. The export customers therefore should pay for transportation the same way as normal customers. Alternatively, normal customers supplying the same flexibility services as export cables to the system have to be exempted from paying for transport like export cables. This current pricing system has no actual connection to the transportation costs from supplier to customer and leads to cross-subsidisation between different customers, in turn distorting the incentives for flexibility. Design of transportation tariffs is important if the systems needs to include storage systems, to avoid curtailment of renewable energy and if district heating have to deliver flexibility.

Both in power systems and in district heating systems transporting costs are primarily fixed costs for investments in networks, while mainly the grid losses are variable. This could lead to the conclusion that future tariff system for both district heating and power transporting should be according to the customer's real costs. Annual costs for measuring, billing, and administration should be paid per year. Fixed costs for capacity and connections paid in RMB per kW wanted or delivered maximum capacity and variable costs paid per kWh delivered. For export connections the price difference between the two price areas should cover the energy loss on the connection and the investments in the connection. If price differences cannot pay for this the connection is too expensive and not competitive. This way the system will be fair, flexible and according to real costs.

When district heating plants have both power producing units and electricity consuming units it works like a power storing system. The incentives for storing can only be achieved when the sum of tariffs and tax paid per kWh on consumption (load) is lower than the difference between power injection (production) prices and power consumption prices, including energy losses. Alternatively, the government has to subsidize electricity consumption or grant exemptions on taxes or tariff for these kinds of solutions. If tariffs and eventually tax are variable depending on power prices—with low tariffs when power prices are low—this could be an alternative way to make incentives for flexible power supply/demand in heat and power sector.

Tax and subsidy system

In Denmark, the tax and the subsidy systems create the largest incentives in the energy system. Creating the right incentives through the tax- and subsidy system is very complex and is often seen as a policy choice rather than as a theoretical matter. Sometimes it is best to disincentivise undesirable fuels or technologies through taxation, and in other cases subsidies for desired fuels and technologies are preferable. From case to case the best method has to be evaluated. Denmark and the European Union have adopted several principles for energy taxation that China could consider:

- Taxation on air emissions (such as SO_2, NO_x, methane) should be the same per kg emission for all fuels.
- Similarly, the CO_2 tax or price for all fossil fuel should be the same per kg of emissions.
- Energy taxes on fossils fuel should be the same per unit of energy content in all fuels.
- Electricity taxation should be based on emissions and energy use from coal power plants as the marginal plant.
- Industry only pays the minimum tax needed to avoid encouraging unfair competition from countries without tax.
- There should be no double taxation. For example, the EU carbon emissions trading scheme (ETS) has no CO_2 tax for entities covered by the ETS, and there is no energy tax on fuel used for power production when there is also a tax on electricity.
- There are subsidies only on electricity production based on renewable technologies and upgraded biogas—there are no subsidies for fossil fuels in Denmark.
- Investment subsidies can be given for new and specific technologies.

The European Commission has set demands for the effect of the subsidising. Subsidy can only be given if it can contribute to fulfil national targets, if it can lead to improvements, which cannot be achieved by market mechanisms, if it is reasonable, if it changes behaviour in a way that leads to further activities, if it does not overcompensate, if it is transparent, and if the negative consequences are limited compared to benefits.

China has often opted to subsidise both fuels and technologies. This could include taxes on emissions, with payments according to the total external cost of emissions at the national level. This gives the right incentive without damaging the economy or industrial competitiveness. The tax and subsidy tool should first be used when other incentives are insufficient to achieve national targets and the need for flexibility.

14.6 Key policy messages

The overall purpose for integrating power and heat sector and establish energy planning is to increase the efficiency, reduce pollution and achieve targets set by government.

Interactions between heat and power sector

To avoid curtailment of renewable power, in addition to using hydro power as storage for the fluctuating power, efficient trading through the power grid, the district heating system's flexibility potential is next most cost efficient solution for creating the necessary flexibility in power systems. At the same time the heating sector becomes more efficient.

If a thermal power plant cannot find nearby use of the heat, the thermal plant may be the first to reduce production when curtailment is needed.

Heat planning

For China a regulated heat planning approach including evaluating environmental impacts and climate effects for establishing an effective, balanced and flexible heat and power sector could be the best way to achieve the national targets. Heat planning should be based on optimising the interaction between the heat and power sectors.

In cold and severe cold areas and even in temperate areas, district heating supply should be measured and delivered for both heating and hot tap water supply all year.

In areas with hot summers and cold winters, and even in areas with hot summers, large buildings should be equipped with ventilation systems, which can be heated in winter direct from CHP plants via district heating system and cooled in summer with absorption heat pumps supplied with heat from CHP district heating systems.

For rural areas and small towns with low building density, electrified heat pumps combined with solar panels for hot tap water in summer seems to be the best solution. Bioenergy boilers can be an alternative in areas with local resources.

In small and large towns with high building density, the first choice will be to utilise excess heat from power plants and surplus heat from industry. Biofuel-CHP or waste incineration CHP should be considered as alternatives if fuel resources are available, if power capacity is needed, and if economic incentives are available.

When the power capacity of thermal CHP plants exceeds the power demand in many hours for the area, the plants have to become more flexible by using storage tanks, bypasses and/or electrical boilers which also increase the heat capacity. Expanding district heating system must in this case be on basis of other heat sources. A part of the solution with to high CHP capacity is to install heat pumps in rural areas and heat pumps in towns without CHP heat capacity available eventually using low temperature surplus heat or other heat sources.

When the heat capacity in CHP plant is too high according to heat demand the solution can be to expand the district heating system.

Waste should always be sorted and the fractions with positive value recycled. The rest not possible to reuse should be used for energy purposes.

Market design

The ongoing process of power market reform which includes the development of short-term markets, namely spot markets operating with short lead times and with at least and hourly time intervals, is a precondition for efficient integration of the flexibility towards the power system that can be offered by the district heating systems.

Besides establishing a power market, incentives for improved flexibility in heat and power sector can be achieved with metering heat sales and creating a future transport tariff system for both district heating and power transport according to the customer's actual costs. Annual costs for measuring, billing and administration should be paid per year. Fixed costs for capacity and connections paid in RMB/kW wanted or delivered maximum capacity and variable costs paid per kWh delivered. For export the price difference between the two price areas should cover the energy loss on the connection and investments in the cable.

Tax and subsidy with the purpose to create flexibility should first be used when other incentives are not enough to fulfil the national targets and the need for flexibility.

15 Demand Side Flexibility

15.1 Summary

Due to the volatility of power generation from RE, more flexibility is needed in the power system in order to better integrate renewable energies and to ensure the stability of the power system.

System flexibility can be increased by exploring and using reactivity potential of the electricity user, called Demand Response, or DR. In the following chapter, DR shall refer to power consuming processes responding to external price signals, such as by the wholesale spot market price volatility or by bidding into balancing power markets (frequency control by reduction or increase of consumption). It should not be confused with the terms "load management" used in Europe which refers to programs and incentives for power consumers to shift their peak load so that it does not occur at the same time as the peak load in the grid.

With flexible processes, energy consumers can contribute to the system integration of renewable energy. This chapter introduces the international cases of Germany and France regarding the use of DR in a market context.

The chapter then describes the current framework for the use of demand side flexibility in China, and offers suggestions:

- Successful implementation of demand response depends on full implementation of ongoing power market reform in China, including establishing markets for spot markets in wholesale power markets, as well as retail markets.
- Demand response also depends on long-term and short-term price signals, and on whether all relevant parties can benefit from compensation for adjusting demand to reflect these price signals. Unbundling grid operation and retail sales could help resolve conflicts of interest that currently prevent efficient transmission of wholesale price signals to retail users.
- Given the complexity of DR, stakeholder involvement is also critical. Stakeholders such as large industrial customers, aggregators, grid companies, and generators all need to understand the framework for DR and who can benefit and participate. This may require marketing campaigns, educational efforts, and pilots for industrial customers to gain and share experiences.

Due to the variability of wind and solar generation, the power system needs greater flexibility to better integrate renewable energies while ensuring system stability. Demand response—enabling electricity users to react to system needs—is an essential element of increasing system flexibility.

In this chapter, demand response (DR) refers to power consuming processes responding to external price signals, such by responding to fluctuations in wholesale spot market prices or by bidding into balancing power markets such as frequency response. DR should not be confused with the term "load management" used in Europe, which refers to programs and incentives for power consumers to shift their peak load so that it does not occur at the same time as the peak load in the grid.

With flexible processes, energy consumers can contribute to the system integration of RE. This chapter introduces two international cases regarding the use of DR in a market context. The chapter then outlines the current demand response framework in China, followed by some ideas on how to increase the use of demand side flexibility in the Chinese power system.

15.2 International experience

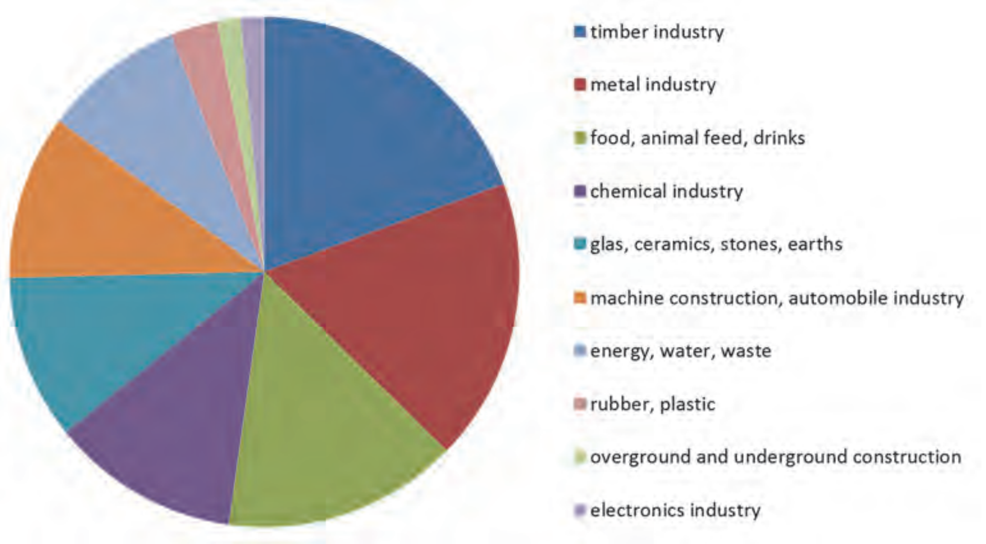
DR in Germany[249]

In the context of the energy transition, Germany has committed itself to reducing its CO_2 emissions (compared to 1990 levels) by 55% by 2030 and by 80-95% by 2050. These targets come together with targets for the share of renewable energy in gross electricity consumption of 65% by 2030 and a minimum of 80% by 2050. In 2017, RE provided 36.1% of the German electricity consumption.[250] This significant share of renewable energy in turn leads to a relatively high degree of variability of power generation. At the same time, grid constraints within Germany create bottlenecks between regions with high RE generation and regions with high (industrial) electricity demand. To properly respond to the need to integrate variable renewable energy on the German grid, the following market segments and service currently allow participation of demand response:

- Balancing power market
- Spot market
- Grid congestion management
- Balancing group management

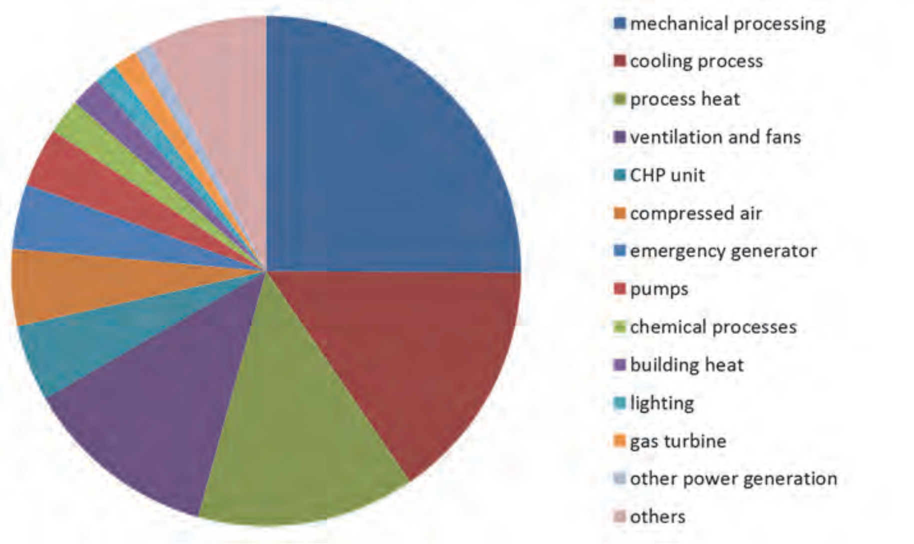
Generally, all measures aim at a flexible control of electricity consumption depending on the current power generation, the use of the available grid capacity or price signals on the power market. Due to the business-to-business-nature of most of those market segments, DR services are currently primarily provided by industrial and large commercial electricity consumers or specialized service providers—so-called aggregators.

Figure 15-1: Distribution by industry of German companies taking part in a survey on DR potentials



For (industrial) companies to provide DR services, they firstly need to identify their flexible loads, defined as electricity-consuming processes whose consumption can be temporarily increased, decreased or shifted to another point in time. Figure 1 and Figure 2 show the variety of industries and the different processes identified as potentially suitable for DR measures in a survey of German companies carried out by the German Energy Agency (dena).[251] Generally, the ability of a company to use flexible loads to provide DR services does not depend primarily on broad characteristics like industry sector or total electricity consumption, but rather on the technical specifications of its processes. These include process controllability, reaction time, and availability of energy storage. In many cases, ancillary processes like heating, cooling, pumps or emergency generators—as opposed to the main processes of industrial production—offer the best risk-revenue ratio for DR services.

Figure 15-2: Number of mentions by processes in a survey on DR potentials amongst German companies



Balancing power market

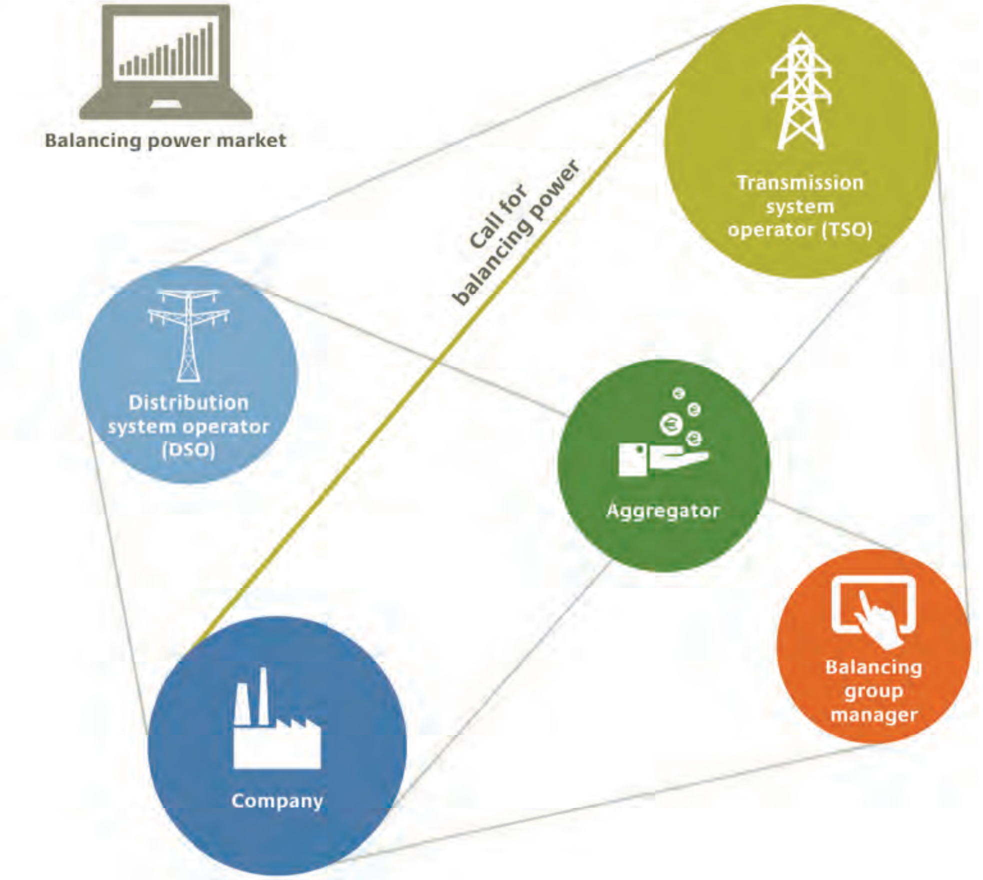
An important market field for DR in Germany is the balancing power market. Germany's transmission system operators (TSOs) use balancing power to keep the grid frequency stable. Companies reduce or increase their electricity consumption depending on the requirements of the grid operator to help balance the grid. TSOs regularly invite qualified bidders to tender for the required balancing power; in these tenders, companies can offer flexible loads as balancing power and hence earn revenue. As a precondition, participating companies undergo a technical pre-qualification process in which TSOs vet the technical specifications of the offered assets.

Since it is crucial for the energy system that balancing power is delivered reliably, aggregators that bundle different flexible loads and power generators in a virtual pool (so-called virtual power plant) both manage the bidding process on behalf of companies offering DR. This increases the reliability of DR offerings and reduces the risk of default on DR obligations. Furthermore, aggregators also enable smaller flexible loads to participate in the balancing power market by taking over administrative tasks and risk management. Thus, aggregation opens up market participation to more potential providers, enhances DR price competition, and enables DR revenue to reach more stakeholders in a non-discriminatory way.

Market players in the balancing market

The following Figure 3 provides an overview of the different market players in the balancing power market and their interaction.

Figure 15-3: Roles and responsibilities of market players in the balancing power market



Each of these players has a dedicated role to play in order to ensure a well-functioning market:

- TSOs are responsible for the safe operation of the transmission system. One element of their work is the use of balancing power (primary and secondary balancing power and minute reserve) for which they centrally and jointly invite to tenders. TSOs are also responsible for the technical pre-qualification of all technical asset that participate in these tenders, including flexible loads.
- Aggregators are energy service providers specializing in the combination and marketing of different assets, including flexible loads. This also allows companies with

smaller flexible loads to have them marketed on the balancing power market. Figure 15-3 highlights the central role of aggregators for the marketing of flexible loads.

- Companies can tap new revenue opportunities by marketing their flexible loads at the balancing power markets and hence contribute to the stability of the electricity grid. The marketing can be done by the company itself or by contracting an aggregator who operates a virtual power plant. Since the availability requirements of the TSOs for all bidders at the balancing market are very high (100%) and non-fulfilment can lead to market exclusion, the use of an aggregator is also a form of risk management for a company.
- DSOs must ensure that the balancing power can be provided effectively to the transmission grid via the distribution grid. They issue the so-called "DSO confirmation" which a company needs in order to get the technical pre-qualification by the TSOs. Flexible loads are often connected at the distribution grid level which is why the cooperation of the DSO is an important element of the pre-qualification process.
- The balancing group managers are responsible for the balance between supply and demand within their balancing group. They issue a confirmation which gives the company approval for the provision of balancing power in their balancing group. In many cases the balancing group manager is also the company's electricity provider which explains the relevance of an agreement between these two parties.

Spot/Intraday market

Another important market field for DR in Germany is the spot market. At the European power exchange (EPEX Spot) short-term agreements for electricity supply are traded. The spot market splits into the day-ahead-market and the intraday-market. At the day-ahead-market electricity supply for the following day is traded; at the intraday-market electricity supply for the current is traded.

Generally, electricity is traded in different time units, with 15 minutes being the smallest unit. This allows for a flexible reaction to changes in the energy supply. Generally, low energy prices occur in times of high supply of energy from renewable energy sources. Companies may shift their electricity demand from times of low generation to times of high generation from renewable energies if they see sufficient price incentive. Introducing the 15-minute unit for electricity trading in 2014 has contributed to a better integration of RE into the electricity system and reduced the amount of balancing power used by TSOs. Volatility and resulting frequency variations are reduced by merely increasing trading activities and thus shifting more balancing responsibility to the market.

Many market segments have processes suitable for DR participation in the spot market. For these processes, varying sport market electricity prices become an important parameter for process planning, alongside traditional parameters like product delivery deadlines, status of material storage, or personnel shift scheduling.

Companies that decide to offer flexible loads on the spot market need to conclude a contract with their electricity supplier. The company and the electricity supplier then regularly exchange information about both the price signals in the spot market as well as possible reactions of the flexible loads. Hence, companies have full control of whether or not to use their flexible loads at a given point in time and realize the optimization of their electricity purchase price.

Grid congestion management

Beside the balancing power market, Germany also has a tender market for interruptible loads (grid congestion management), also managed by the TSOs. The grid congestion management helps the grid operators address local grid congestion needs by activating flexible loads in a given area. The market for grid congestion management is limited to large consumers with a minimum load of 5 MW. As in the case of the balancing power markets, companies that want to participate in this market must undergo a technical pre-qualification process to determine whether or not they fulfil all technical requirements (grid connection, minimum availability, controllability, etc.).

The grid congestion management market includes two kinds of products: immediately interruptible loads that have to react within 350 milliseconds and which are automatically activated by frequency; and quickly interruptible loads with a reaction time of 15 minutes. Companies can offer flexible loads at a weekly call for tenders held by the TSOs. Unlike the balancing power market, there are regulatory limits for the price offers (Euro 500/MW and week and Euro 400/MWh). Flexible loads can be offered simultaneously in the balancing power market and in the market for interruptible loads. Companies will only receive remuneration for the market field in which the flexible load is used. To reduce the administrative burden for the electricity consumers, interruptible loads can also be pooled by aggregators and offered jointly in tenders.

Balancing group management

Lastly, balancing group management is another way for companies to market their flexible loads through bilateral contracts. If electricity supply and electricity demand become unbalanced, the balancing group manager runs a risk of penalty by the TSO, which would then need to activate balancing energy. To avoid this cost, the balancing group manager can conclude contracts with companies to temporarily adjust their electricity consumption. Hence, the balancing group manager uses the companies' flexible loads to address an imbalance in their balancing group and thus avoid possible balancing energy costs. Since this use of flexible loads is based on bilateral contracts, the actual usage and market size are unknown.

Market development

In recent years, two developments with great relevance DR measures took place in German markets. First, prices on both the balancing power market and the intraday market as well as price spreads on the intraday market have decreased, mainly due to increased market activity and hence higher market liquidity. This has implications for DR since it reduces the possible revenues for the marketing of flexible loads.

The second development concerns a shift of market activities towards intraday markets. Figure 4 shows the volume of the balancing power market and the intraday market from

2011 to 2018. This figure highlights that while the balancing energy needed during these years ("calls for control reserve") decreased considerably, the amount of energy traded on the intraday market at the same time has significantly increased. It has to be considered that at the intraday market the same actual slice of supply and demand can be traded various times. This development can partly be ascribed to a reduction of traded time intervals on the intraday market to 15 minutes, which allows traders and aggregators to react much more precisely to the difference between reality and forecast, such as in the case of RE when overcast or storm fronts occur. Further decrease of the trading intervals and the gate closure time for fulfilment of the traded contracts is currently being tested.

Figure 15-4: 2011-2018 balancing market and intraday market volume[252]

DR in France

The regulatory framework for DR in France is considered to be among the most advanced in Europe.[253] The different measures are grouped into the following DR markets:

- Balancing power market
- Spot market
- Capacity market

The overall technical potential for France cumulating the industrial (about 70 percent) and commercial sector (about 30 percent) is estimated to be between 6.5 and 9.5 GW. Depending on remuneration levels, the economically accessible DR capacities are estimated to be between 1.5 and 5 GW.[254]

Balancing power market

The balancing power market is divided into several products: the automatically activated primary and secondary reserve (FCR and aFRR), the manually activated frequency control reserve (mFRR) and tertiary reserve (RR). These markets were opened for participation of flexible loads in 2007. In the past years, adjustments were made in order to level the field for market participation of flexible loads. E. g. flexible loads that are bundled in a pool now only have to fulfil technical pre-qualification requirements as a pool and not as a single asset.

For FCR and aFRR, consumers that offer flexible loads receive a fixed remuneration by the French TSO RTE both for the provision (capacity price) and for the actual call (working price). For mFRR and RR, a pay-as-bid tender scheme based on the working price is in place. In a separate capacity tender scheme additional mFRR and RR is acquired by RTE if needed.

Companies participating in the balancing power market come from the following sectors: metal industry, chemical industry, paper, food industry, airports and hospitals.

Spot market

The French spot market allows for both implicit and explicit marketing of DR. The implicit marketing gives electricity consumers the chance to optimize their consumption according to a specific multistage tariff linked to the variability of electricity prices on the spot market.

In 2013, the French regulator created the NEBEF mechanism for explicit DR in the spot market. Flexible loads can now be offered directly at the spot market – either by the consumer or by an independent aggregator. Offering the load at the balancing power market simultaneously is possible. Pre-qualifications as well as all other relevant processes such as data exchange and remuneration are overseen by the French TSO RTE.

The structure of remuneration for the different stakeholders is complex: In addition to the revenue made by aggregators and the premium providers of flexible loads receive from their aggregators, electricity suppliers receive compensatory payments for their missed supply.

Since the NEBEF mechanism was introduced the activation of flexible loads has increased significantly from 620 MW in 2014 to 3,149 MW in 2016.[255] At the same time, due to falling prices and decreasing price spreads to realize revenue with marketing flexible loads at the French spot market have declined.

Capacity market

Since January 2017, energy suppliers are assigned capacity obligations each year. This obliges them to ensure they produce sufficient capacity to meet the actual consumption of their clients during peak periods. The capacity certificates, sold by energy producers and sites that can decrease their power capacity on demand, are exchanged by auctions and on OTC. One capacity certificate is equivalent to 0.1 MW. Similar to the French spot market, flexible loads can participate at this capacity market indirectly, i.e. through their supplier, or by direct certification from the French TSO RTE. Following the introduction of this capacity mechanism in France, Epex Spot set up a market place for auctions for French capacity guarantees. The first auction was held in December 2016. In the following years, the market will be organized through several auctions per year. Standardized capacity guarantees will be traded for respective delivery years.[256]

15.3 The current framework for demand side flexibility in China

In the past, China's power demand side generally adopted one-way regulation by administrative means such as orderly power consumption. This includes strengthening power consumption management and changing the patterns of power consumption through legal, administrative, economic and technical means. Measures included peak shift, peak avoidance, rotating days off, power transfer and load control power restriction. These measures helped system operators avoid unplanned power rationing, standardize the power consumption order, and minimize the adverse impact of seasonal and time-consuming power supply and demand conflicts on society and enterprises.

Orderly power consumption is led and promoted by governments at all levels and relevant government departments, mobilizing power supply enterprises and power consumers to participate and cooperate. According to the Administrative Measures for Orderly Power Consumption, local governments should take administrative, economic and technical measures to manage power consumption, and require orderly management according to the following order: first, shifting peak load of power consumption to other periods; second, peak avoidance, realized through interruptible load; third, power restriction; and finally, power rationing.[257]

In addition to orderly power consumption, retail prices are another important starting point of demand side management. Peak-valley pricing has a significant social benefit in effectively adjusting the peak-valley difference of power consumption. At present, the peak-valley difference of the grid in China is set such that the price ratio should satisfy the goal of peak shaving and the economic benefit. Compared with higher peak-valley price difference level in foreign countries, China's peak-valley price ratio is generally only 2-3 times. At this level, it is difficult to motivate power consumers to change their ways of power consumption to achieve peak shift.

To promote the balance of power supply and demand and further release the flexibility potential on the load side, the National Development and Reform Commission launched a comprehensive demand side management pilot scheme in 2011, selecting four cities as pilots: Beijing, Tangshan, Suzhou and Foshan. The pilots aimed to reduce the peak demand for electricity in industrial facilities and commercial buildings and improve the efficiency of power consumption.

At present, China's demand side management is still mainly based on orderly power consumption management, with peak-valley time-of-use price or interruptible load projects implemented in some regions. However, in recent years, the state has issued relevant policies to promote the implementation of DR, and has transitioned from orderly power consumption to demand side response. Different from the traditional orderly power consumption scheme, the power DR uses market means to allow users to voluntarily and temporarily take measures to change the original power consumption mode during peak load hours of the grid, obtaining subsidies and incentives or price concessions.

Urban Pilots of DR

In 2012, the National Development and Reform Commission and the Ministry of Finance issued the Interim Measures for the Management of Central Fiscal Incentive Funds for the Urban Comprehensive Pilot Work on the Electricity Demand Side Management, which rewards RMB 440/kW in the eastern region, RMB 550/kW in the central and western regions, and RMB 100/kW for peak power load temporarily reduced through DR.[258] Since 2013, comprehensive urban pilot projects of demand side management have been organized in Beijing, Tangshan, Suzhou and Foshan.

DR in China today can be divided into two types: a) Agreed DR, which reduces the load according to the agreed amount during the DR execution period through the DR Agreement; b) Temporary DR: when the grid is short of power, temporary peak shift will be made according to the DR Agreement. DR is basically dominated by the government and power companies, with load aggregators and power consumers participating voluntarily. DR agreements in Foshan, Suzhou and other places are all signed by the Commission of Economy and Information Technology with power companies, load aggregators and power consumers. In Shanghai, the model of consumer's self-subscription DR was piloted, relying on customer initiative to participate.

On July 9, 2014, Shanghai became the first city in China to complete its DR pilot, with a response load of about 55 MW completed. This consisted of 28 commercial building consumers and 7 industrial consumers.

In the "Several Opinions of the CPC Central Committee and the State Council on Further Deepening the Reform of the Electric Power System" (G.F. [2015] No. 9) released on March 15, 2015, the National Development and Reform Commission gave guidance on promoting the sustainable and healthy development of clean energy, strengthening power demand side management, accelerating the reform of power transmission and distribution prices, and promoting trans-provincial electricity market transactions. The implementation of these policies requires additional detailed rules.

Table 15-1: Summary of Electricity DR Pilots in 2015

Pilot	Time	Load Reduction (ten thousand kilowatts)	Status of Consumers
Foshan, Guangdong	July 30 August 13	4.2 13.7	96 enterprises participated in the DR program, of which 87 enterprises participated through 3 load aggregators.
Suzhou, Jiangsu	July 30	23	24 power consumers and 5 load aggregators participated in the DR program.
Beijing	August 12 August 13	7 6.6	17 load aggregators and 74 consumers participated in the program.

Jiangsu	August 4	165.77	557 consumers and 8 load aggregators (586 signed agreements); 513 consumers actually participated in the DR program.
Shanghai	September 7	0.4	15 commercial buildings in Huangpu District participated in the DR program.

In terms of incentives, a temporary reduction subsidy of RMB 130/kW (10 pilot projects) has been implemented in Foshan; while in Jiangsu, a seasonal peak price policy has been adopted for major industrial consumers of 315 kVA and above, with a peak price increase standard of RMB 0.1 /kWh, and the revenue increase would be mainly used for load subsidy for DR, with a highest subsidy standard of RMB 100/kW; the price discounts has been implemented in Shanghai in accordance with the reduction of power consumption, with the highest standard of RMB 2/kWh, whereas according to the survey feedback from the responding participants, it was hoped that the subsidy standard could be raised to RMB 8-10 /kWh according to the power consumption.

In terms of project design, the DR participants in Foshan were mainly industrial enterprises, with DR projects mainly focusing on day-ahead notification. The Jiangsu pilot consisted of DR with day-ahead notification for industrial consumers, and the pilot also designed a program for DR with real-time notification for non-industrial air-conditioning consumers. Shanghai piloted a multi-project design of industrial consumers, commercial building consumers and resident consumers, and also experimented with automated DR with real-time notification.

During the implementation of China's DR programs, the functions and positioning of load aggregators have gradually become prominent. Shanghai and Foshan organized training for consumers, configured consumer DR platforms, debugged load-control equipment communications, performed overall monitoring of the process, and implemented reduction strategies for consumers. The Jiangsu pilot included the capability of monitoring and control DR equipment in real time through DR terminals, laying the foundation for automated DR.

In terms of the business model for demand response, the Shanghai pilot implemented DR consumer electricity deduction, while load aggregators had no model for making profits. In the Foshan and Jiangsu pilots, load aggregators performed unified management and participated in the implementation of DR events throughout the process depending on the results of bilateral negotiations between load aggregators and participating power consumers.

In terms of market customer development, Shanghai issued a DR guidance document, and the government instructed load aggregators to organize training for power consumers. In Foshan and Jiangsu, the DR centre, load aggregators and responding consumers signed formal contracts or agreements, combining consumer self-reporting with market development, and data acquisition terminals were installed free of charge or shared by load aggregators and consumers.

In terms of technical implementation plan, regarding Shanghai and Foshan's day-ahead notification project, the response consumers reduced the load by themselves, load aggregators implemented information collection without active control, and displayed dynamic load in real time through the platform or mobile phone application (APP). The load control terminal in Jiangsu could be monitored and controlled with the consumer's consent, and the consumer could inquire about the power company's real-time power consumption information through a mobile application. DR load baseline measurement is central to balancing the interests of power companies and consumers. For demand response load calculation, the ultra-short-term load baseline calculation method was studied in Shanghai according to consumer load characteristics and applied in the pilot work. Load aggregator platform data was only used as a reference for response load evaluation. The baseline algorithm directed by the National Development and Reform Commission was followed in Foshan. The 5-day maximum load method was implemented in Jiangsu to determine the baseline. The consumers can confirm the effectiveness of DR participation by themselves and proposed a review request to the aggregator.

Market trading is the most fundamental goal of DR, and it is also a long-term model of power demand side management. Due to the intermittent nature of RE and distributed energy failure conditions, demand side response resources are a good balance measure, characterized by large regulation potential and low cost. At present, Shanghai, Foshan and Nanjing have not formed electricity trading markets based on DR, while Guangdong is currently trying to establish electricity trading platforms based on direct supply from large consumers.

Situations of Shanghai Power DR Pilots

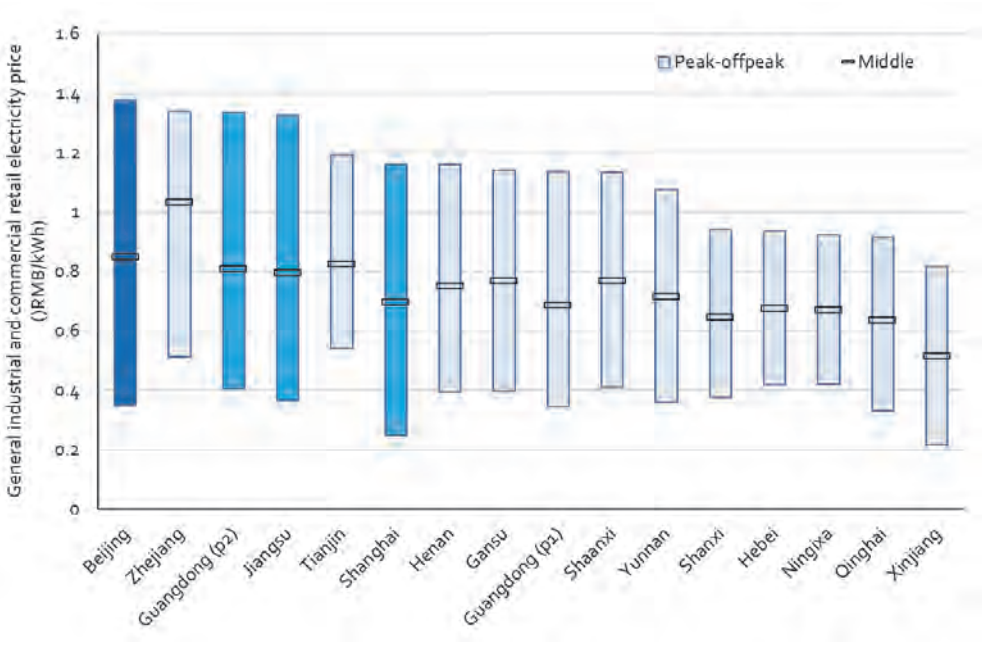
As a leading DR pilot city, Shanghai has accumulated significant experience in the exploration of DR markets. According to the relevant requirements of the National Development and Reform Commission, under the organization of Shanghai Municipal Commission of Economics and Information, the first pilot test of Shanghai's power DR was officially launched in 2014 at the State Grid Shanghai Municipal Electric Power Company. In June 2018, the State Grid Shanghai Municipal Electric Power Company first implemented a large-scale "valley filling" type of power load DR in Shanghai, involving 88 individual electricity consumers and 5 load aggregators (aggregating 522 consumers), covering all types of controllable loads such as industrial production peak shift, self-owned power plants, cooling-heating-power cogeneration, ice storage air conditioning units, electric energy storage facilities, public electric vehicle charging stations, and residential electric vehicle charging posts. This load DR has a single maximum increase of 1,059,300 kilowatts, with an average valley filling load of 872,800 kilowatts during the response period. This represents 8.42% of the total low load of the power grid at night, with the highest proportion of low load, the most complete type of participating load and the largest number of participating consumers in the current domestic similar power DR. In terms of response mechanism, Shanghai grid's load DR mainly adopts flexible incentive mechanism, guiding consumers to actively reduce peak load or add valley bottom load, from passive acceptance of instructions to active participation in regulation.

Peak-Valley Time-of-Use Prices

Retail electricity prices are an important way to guide rational use of electricity and explore the potential of consumer DR. There are several dimensions to China's end-user electricity prices. The types of power consumption in most areas include household electricity, agricultural electricity, general industrial and commercial electricity and large industrial electricity. In most areas, general industrial and commercial electricity pay only energy unit prices, while large industrial electricity customers use a two-part tariff with a demand charge and a basic electricity unit price. The demand charge includes the maximum demand and transformer capacity, which enterprises can select according to their anticipated needs. The average price of electricity for large industrial customers is lower than that of ordinary industrial and commercial electricity. When the demand for electricity is stable and the basic electricity price is considered the electricity price used in large industries is still generally lower than that of ordinary industrial and commercial electricity.

In April 2016, the State Council proposed to promote electricity price equalization for industrial and commercial customers, allowing large commercial enterprises to participate in direct electricity trading, and carry out pilot projects where commercial consumers independently choose between paying the average commercial tariff or the peak-valley time-of-use price. According to incomplete statistics, after the National Development and Reform Commission issued the Notice on Reducing General Industrial and Commercial Electricity Prices[259] in April 2018, 16 of 34 provinces, municipalities, and autonomous regions in China issued peak-valley electricity price tables. Jiangsu, Zhejiang, Hebei, Shanxi, Anhui, Fujian, Shandong, Henan, Hubei, Guangdong, Hainan, Guizhou, Yunnan, Shaanxi, Inner Mongolia, Guangxi, Ningxia, Beijing, Tianjin, Shanghai, Chongqing have adjusted their general industrial and commercial electricity prices. 13 have peak-valley electricity prices, including Beijing, Guangdong, Hainan, Hebei, Jiangsu, Ningxia, and Chongqing. Among the provinces and cities that have not announced price adjustment plans are Gansu, Qinghai, Shanxi, Shanxi, Shanghai, Tianjin, Yunnan and Zhejiang. Among the provinces and cities that have not announced price adjustment plans, there are three provinces that implement peak-valley electricity prices, namely Gansu, Qinghai and Xinjiang. Figure 1 shows the peak-valley time-of-use price of industry and commerce in some provinces and cities, of which Beijing, Guangdong, and Jiangsu have a large difference in peak-valley price, while Shanxi, Hebei and Ningxia have a low difference in peak-valley prices.

Figure 15-5: Peak-valley Time-of-Use Price of Industry and Commerce in Different Areas



Note: The data in the figure shows the peak-valley time-of-use price of less than 1,000 kilowatts for general industry and commerce. Guangzhou (1): Yunfu, Heyuan, Meizhou, Shaoguan and Qingyuan; Guangzhou (2): Guangzhou, Zhuhai, Foshan, Zhongshan, Dongguan; the two-part summer peak-valley electricity price is referred to in Shanghai; and the peak-valley electricity price in dry season is referred to in Yunnan.

In July 2018, the National Development and Reform Commission issued the Opinions on Innovating and Perfecting Price Mechanism for Promoting Green Development, proposing to use market-oriented mechanisms such as peak-valley price difference and supplementary service compensation to promote energy storage development. It can be predicted that with the further widening of the peak-valley price difference in various regions, its guidance to demand-side electricity consumption will be strengthened.

Problems and Prospects of Releasing Demand Side Flexibility

With the deepening of power market reform, market-oriented mechanisms such as DR are becoming the main means of releasing demand side flexibility resources. However, the current demonstration projects of DR in China also reflect several problems:

DR requires additional up-front investment in metering and monitoring

In addition to accurate measurement, DR also requires accurate data transmission. Measuring equipment and online monitoring system are important support technologies for DR. At present, the online monitoring equipment for DR in China is invested by power grid companies or load aggregators to install and maintain for consumers, while the online monitoring systems for DR are invested and built by the government and grid companies.

With the promotion and development of DR, a large amount of money still needs to be invested in the installation and maintenance of metering equipment, data transmission and maintenance.

Present DR subsidies have several shortcomings

The current policy provides an incentive of RMB 100/kW for temporarily reducing peak power load through DR. All localities have formulated management measures and employ specially established funds for demand side management. These funds draw on surcharges levied on retail electricity sales, increased electricity revenue from the implementation of differential prices, and other funds. Subsidies face challenges optimising the allocation of resources, and policy-makers lack a mechanism for fining those who fail to comply with DR requests. In addition to power consumers and load aggregators, participants in DR also include government departments and power companies. DR involves the processes of load control and subsidy distribution, and this creates potential contradictions among participants, given uneven distribution of benefits.

DR in China also faces technical barriers

Most of DR projects in China are carried out under individual agreements. Many real-time demand response events are not automatic. DR events reduce peak load on the power grid, but the response speed of DR in China is slow, response magnitude is uncertain, and peak shaving capability is poor.

In the future, China should further improve the electricity price mechanism and enrich the types of DR that can participate. China should also improve real-time information transparency regarding local generation and load, expand the scope of participation beyond large customers and encourage small and medium-sized customers to participate, and discuss the DR bidding mechanism on the basis of practical experience. As various energy storage technologies become more widely available, DR will increasingly be capable of participating in grid frequency modulation and peak regulation. In addition, the spot market has a great demand for consumer-side DR.

15.4 Suggestions for expanding demand response in China

DR is crucial to helping the grid incorporate increasing proportions of variable renewable energy. The electricity system of the future will need to incorporate existing and future flexible loads efficiently. Based on the international experiences given above, we suggest several ways to improve this framework for DR in China:

Implement transparent wholesale and retail markets with real-time price signals for DR

First and most importantly, plans for a fully-fledged, competitive Chinese power market with dynamic price signals in both wholesale markets and retail markets should be implemented. Both international examples provide insights on how well-designed market structures are a necessary precondition for the efficient implementation of DR into the energy system. With the use of clear price signals in the market, the different fields of application for DR can be incentivized and used (overall and local balance of supply and demand, overall frequency control and local grid congestion management). Only a transparent and open market allows for industrial and commercial companies as well as DR aggregators to assess their individual potential to deliver flexible loads.

Offering flexible loads for DR should be a free decision of market players based on the potential added-value and business case. A smart market setup with the right incentives is needed to make this work in order to achieve a macro-economically efficient solution. Coercion (in the form of obligatory bilateral agreements) should only be exerted upon those able to provide flexible loads to ensure system stability and in case all other means are exhausted.

Increase compensation for DR to reflect its full system value

Second, all relevant market players need to have a financial or other interest to engage in DR. As a starting point, the level of remuneration for companies or aggregators who are providing and bundling flexible loads needs to adequately compensate for their efforts.

With grid operation and electricity sales in China currently held by a single entity, the incentive for third parties to engage in DR measures is limited. The example of the French system may give ideas for potential solutions for this conflict of interest by introducing a compensatory payment for the energy provider’s missed revenue. However, while this may reduce the reluctance of energy providers to engage in DR, it reduces at the same time the possible revenue of the companies who offer their flexible loads. A second option to address the conflict of interest is to unbundle grid operation and electricity sales. This would allow independent sales and trading activities and development of optimization strategies with their customers by the energy providers.

Enhance stakeholder involvement and information

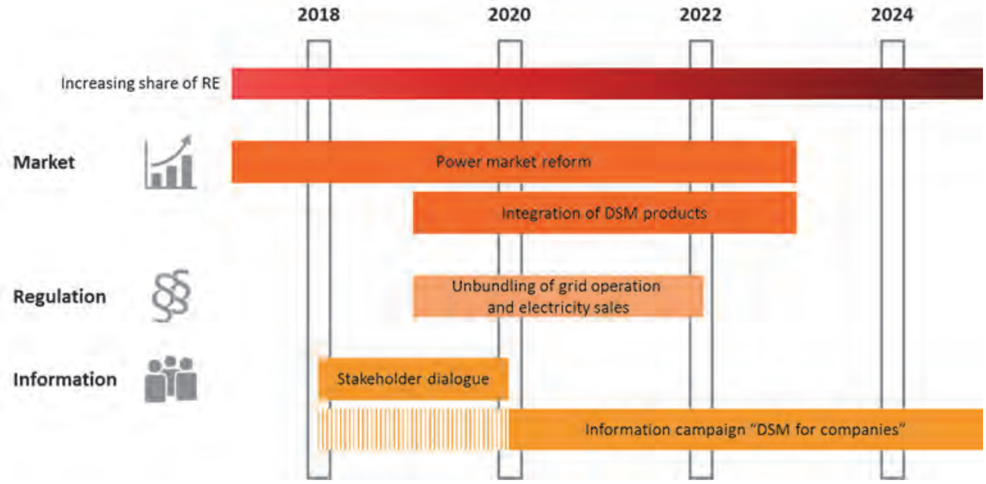
Third, to successfully develop DR in a market/country, there needs to be a high degree of knowledge regarding the framework conditions among all relevant players. Information campaigns could be used to spread knowledge about the functionalities of DR and promote it both as a relevant part of an efficient energy transition and as an opportunity for a company's energy management strategy.

At the beginning, a dialogue between relevant stakeholders (grid operators, existing load aggregators, major industrial companies etc.) would help to set-up a common understanding of DR and its purpose. Support for the necessary energy sector reforms could be derived from such an exchange.

International experiences show that the establishment of DR in companies is a complex process. Widespread information measures will be a necessary, aiming at (industrial) companies with a focus on familiarizing them with the topic, on identifying flexible loads and on defining steps towards marketing them in collaboration with aggregators.

Practical experiences regarding the successful marketing of DR through pilots with both (industrial) companies and aggregators could be used and highlighted as positive examples.

Figure 15-6: Timeline for possible steps to foster the use of DR in China



16 Distribution grids: A paradigm shift

16.1 Summary

In centralized power systems with large thermal power plants, distribution grids are used to distribute electricity from the transmission grid to end consumers like households. In energy systems with increasing shares of RE, the role of distribution grids changes since they also become the connection point for the electricity feed-in of distributed generators. Power flows will become increasingly bi-directional, creating the need for new concepts to address the technical and procedural challenges that result from this change. This chapter describes briefly the situation in distribution grids in China, noting the following key points:

- China has increased the automation of its distribution grid somewhat, but the potential for improvement is still very large.
- The distribution grid still suffers from relatively low levels of reliability.
- The distribution grid is unable to cope with high levels of small-scale distributed energy, storage, and electric vehicles.

As a result, the chapter emphasizes the need for China to rapidly upgrade and modernise distribution grids with smart grid technology, create policies to incentivise distribution grid operators to accept more distributed energy, and improve distribution grid pricing and business models to this end.

The chapter also presents a case study about upgrading distribution grids in New York, noting that policy incentives have been critical to enabling the utility—which owns the distribution grid—to save money on distribution grid upgrades by investing in non-wires alternatives such as distributed energy and demand response. The situation of Germany's distribution grid also shows how widespread deployment of renewable energy has both challenged the grid and also provided new opportunities: Germany has deployed new technologies for voltage control and reactive power, but it has also been critical to enable generators (including distributed renewable energy sources) to play a role in grid services such as offering reactive power.

16.2 The Chinese distribution grid – realising economic and social development

Current situation and challenges of the construction of Chinese distribution grid

The distribution grid is an important public infrastructure for national economic and social development, and it plays an important role in connecting the power system with users, supplying electricity to users and distributing electricity.

The Chinese distribution grid has been under construction for more than 60 years, and its voltage levels have increased over time. At present, the Chinese distribution grid is divided into high-voltage, medium-voltage and low-voltage distribution grids according to voltage levels. Among them, the high-voltage distribution grid is usually 35-110 kV, the medium-voltage distribution grid is usually 6-10 kV, and the low-voltage distribution grid is 220/380 V. In large cities with high load ratios, the 220 kV grid also has a power distribution function.

The Chinese distribution grid can be divided by function into urban distribution grids, rural distribution grids and factory distribution grids. Considering the safety level of power supply, the Chinese distribution grid usually employs structures such as double-loop networks and single-loop networks. For first-tier cities, China grid planners strive to build a network architecture with high reliability and flexibility level, fully realizing bilateral power source and loop network structure, strengthening the connection ratio of medium-voltage lines, and improving the capacity of load transfer. For other cities and towns, in combination with the local economic and load development, such policies can resolve problems such as insufficient N-1 capacity of high-voltage distribution grids and cases where a single feeder line connects to a single transformer near the load. Hence, problems such as insufficient subsection and line connection of medium-voltage distribution grids are gradually alleviated. The construction of rural distribution grids is mainly to improve the power supply radius.

The distribution grid involves many voltage levels with a wide coverage, and the project is complicated with a small scale. At the same time, it is directly oriented towards the society, and is closely related to urban and rural development planning, diversified demands of users and the development of renewable energy. The construction demand is largely random and uncertain, and there is still a significant gap between China and the international advanced grids in many respects.

The current situation and challenges of the construction of Chinese distribution grid are as follows:

China has improved distribution grid automation, but huge potential for improvement remains. China has continuously increased investment in distribution grids. In recent years, the power transformation capacity and line length of distribution grids have multiplied, and the power supply capacity has greatly improved, which has played a huge role in the rapid development of urban and rural economy and society. Advanced relay protection device, substation integrated automation systems, grid dispatch automation systems, and grid safety and stability control systems are widely used.

The automation level of Chinese distribution grid still needs to be improved compared to that of Tokyo distribution grid, which is 100% covered. By the end of 2015, the number of lines covered by distribution automation of State Grid accounted for only 15% of the total number of distribution lines, and did not exceed 25% by the end of 2016. Some first-tier cities in China have achieved the monitoring and controllability of distribution grids, while the operational monitoring and automation control capacity in other regions are still insufficient, and power distribution automation still has great potential for improvement.

The intelligent interaction of the distribution grid is still developing, and technology R&D and standard-setting are relatively weak. To adapt to the rapid development of distributed energy, China is advancing intelligent microgrid construction. This mainly refers to the smart energy comprehensive utilization LAN with multi-energy complementary of various distributed energies such as wind, PV and natural gas and with source-network-load coordination and interaction based on the construction of local distribution grids. With a high proportion of renewable energy access, the primary balance of local energy production and consumption can be achieved through energy storage and optimized allocation.

However, China's intelligent microgrid development is still in its infancy, mainly consisting of pilot projects such as microgrids in remote areas, island microgrids, and urban microgrids. However, it must be noted that China's microgrid technology is not yet fully mature. The construction of the pilot projects is mainly used for the research and verification of key technologies of microgrids. China has not yet completed the definition and design specifications of microgrid, and the requirements on reliability and energy storage. In addition, China currently lacks mature business or operational models for microgrids, thus restricting the development of microgrid. The country also lacks a microgrid incentive policy or standards and systems for assessing the energy efficiency, reliability of power supply and provision of services such as voltage support in microgrids.

The reliability of distribution grid power supply needs to be improved. Since the end of the last century, when the country underwent a severe and long-term shortage of power, China has focused power plant construction for power system development. The construction of the Chinese distribution grid experienced a shortage of investment at the end of the 20th century, increased passive investment at the beginning of the 21st century, and increased investment during the period of the 12th Five-Year Plan.

Today, the construction of distribution grid is a priority of China's grid development. In 2016, China's reliability rate is about 99.8052%, and the average power outage time is 17.11 hours per household. The urban power supply reliability rate is about 99.9408%, the average power outage time is 5.20 hours per household, whereas the rural power supply reliability rate is about 99.7583%, the average power outage time is 21.23 hours per household.

China's outage figures are presently poor compared with several advanced industrial countries. The power supply reliability index in the United States is relatively stable. Regardless of major events, the average annual outage time is 2.23 hours per household. Considering major events, the outage time is estimated to be 3.8-5 hours per household. Japan's power supply reliability rate has maintained reliability over 99.99% since 1986. The average outage time is below a standard of 0.876 hours per household. Nationally, only in Beijing, Tianjin, Shanghai and Jiangsu, the reliability rate exceeds 99.9% and the average outage time is less than 10 hours/household. The reliability rate in more than 88.6% of provinces and cities is lower than the standard for high grid reliability.

Although the construction of Chinese distribution grid has been continuously strengthened since the start of the 12th Five-Year Plan, the power supply reliability is still in its infancy. Especially with the large-scale deployment of distributed energy and EV charging, in the near future distribution grids will face new and challenging requirements.

Distribution grids are not well adapted for distributed renewable energy. China's 10 kV grid structure is still weak, and there are still a large number of 10 kV lines that are not interconnected. The gap between urban and rural grids is significant, and the interconnection proportion of rural grids is only one-third of that of the urban grids. Traditional distribution grid planning and design methods are usually unable to consider or seldom consider the integration of distributed power sources and adjustable loads; rather, they are designed for the maximum load.

Distribution grid planning also fails to consider control functions such as active power regulation, and lacks the technical capability for active regulation and control. Therefore, it is currently not possible for distributed power source to participate in system voltage and reactive power control and provide ancillary services to the energy system.

In addition, the traditional distribution grid has a weak ability to facilitate adjustable loads. Controllable technologies such as EV charging, electric water heaters, washing machines and lighting equipment in the distribution grid can adjust power consumption and shift consumption as needed. These loads can become an important power balancing resource. At present, due to little consideration of adjustable loads and lack of technical means in planning and design, the grid is currently designed only for loads that passively absorb power from the grid.

Suggestions on the development of the Chinese distribution grid

Accelerate the construction of modern distribution grids. China should accelerate the construction of modern distribution grids that are coordinated between urban and rural areas. Distribution grids should be safe and reliable, economical and efficient, technologically advanced, environmentally friendly, and they should be compatible with a well-off society, strengthen the unified planning of distribution grids, and improve overall system standards.

Central city districts will build distribution grids with high standards focused on high reliability. In combination with the national new urbanization process and development needs, urban areas will continue to build out distribution grids while seeking to pro-actively anticipate access for renewable energy, distributed power sources and EV charging infrastructure. China will also comprehensively build "Internet +" smart energy, which includes:

- promoting the integration of distributed energy and Internet technology, active distribution grid technology and energy storage technology,
- fully integrating intelligent energy production and consumption infrastructure, multi-energy collaborative and integrated energy networks, and energy and information communication infrastructure,

Promote efficient use of distributed renewable energy. Distributed renewable energy has been widely developed in China over the last several years. Distributed energy connotes not only technological innovation, but also the transformation of the energy supply model. However, distributed renewable energy challenges the distribution grid due to its fluctuating output.

The development of distributed renewable energy is closely related to urban construction, and involves many infrastructure sectors. In the future, distributed renewable energy should be incorporated into overall urban planning, and be coordinated with planning of the urban grid, gas pipe networks, heating and cooling pipe networks, and other infrastructure. The city's energy layout and scale of network infrastructure construction should be considered as a whole. China should strengthen relevant technical research and establish a unified and complete distributed renewable energy standard system to provide a solid foundation for the development of distributed energy. The power market reform now underway is also an opportunity to improve pricing mechanism for distributed renewable energy.

Explore new models for incremental distribution grids. China should increasing diversify its overall energy supply. In addition to providing value-added services such as providing reliable electricity to end-users, distribution grid operators can provide services such as power generation, heating, gas supply, and water supply. Distribution grid operators can also study the impact of comprehensive utilization, transformation and substitution of different energy sources on the distribution grid. A smart energy distribution grid is one that helps users benefit from improved integration of multiple energy sources, via online information platforms potentially incorporating aspects of the sharing economy. We should encourage diverse pricing models for these types of new distribution grid services. In turn, this entails consideration of the differences between incremental distribution grids and existing distribution grids, including the impact of new technologies and new business models. It is possible that the pricing mechanism for the additional distribution grid investments will need to differ substantially from traditional distribution grids.

Apply advanced big data technology. China should accelerate the installation of smart meters and improve the measurement efficiency for residential electricity consumption. This will entail promoting an energy system involving digitalization and internet of things technology. An advanced metering infrastructure is required to achieve the measurement, collection, storage, analysis and use of user electricity consumption information. In addition, China should build a complete grid security system to ensure the safe operation of the grid.

16.3 Case study: Optimising cost of distribution grid extension in New York

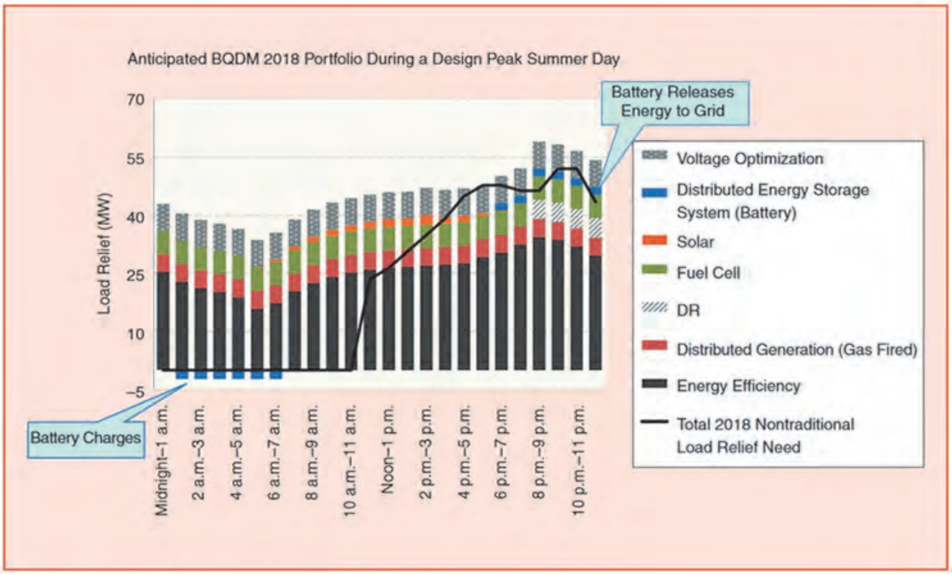
In many countries around the world, renewable energy is increasingly used to produce electricity, which might necessitate expansion of the transmission and distribution grid. Many areas also need to upgrade power grids due to aging infrastructure. Since this need of grid upgrades or expansion can result in high cost, planners and policy-makers are interested in new approaches that can reduce this cost. This section describes New York's efforts to optimise the cost of distribution grid upgrades in New York.[260]

Excessively high cost by conventional grid upgrades

In the state of New York, several different electric utility companies have been grappling with multiple grid-related challenges, including an aging infrastructure that likely would require significant upgrades, a high degree of exposure to natural gas prices, growing peak electricity demand, and rising electricity rates for consumers.[261] To help address these issues, utilities and regulatory authorities in 2014 initiated a structural transition of the state's energy system called Reforming the Energy Vision (REV). The primary objective of the REV initiative is to build a clean, resilient, and more affordable system for state residents by increasing consumer participation and renewable generation.

Under the larger REV process, Con Edison, an investor-owned utility (IOU) that serves more than 3.3 million customers in New York City and Westchester County, sought an innovative program to use distributed energy resources (DERs) in new and innovative ways to either complement or offset traditional utility grid upgrades.[262] In Con Edison's service territory, the New York City boroughs of Brooklyn and Queens are experiencing high growth in both population and electricity demand that is estimated to overload certain sub transmission feeders by up to 69 megawatts (MW) for up to 48 hours during the summer months.[263] To alleviate the possible future overload hours, Con Edison estimated that an investment of approximately US$ 1 billion would be needed for grid expansion under a business as usual (BAU) scenario reflecting the high cost of infrastructure in a congested urban environment with assets both above and below ground. This high cost estimate was part of the impetus for looking at non-traditional ways of alleviating the constraints on the distribution grid.

Figure 16-1. Anticipated BQDM portfolio during a design peak summer day [264]



Alternative approaches for higher cost efficiency

As an alternative to the BAU approach, Con Edison proposed the Brooklyn-Queens Demand Management (BQDM) Program under its distributed system implementation plan. At approximately US$ 200 million, the program aims to defer the need for traditional grid expansion investments by several years. Recent filings also suggest that Con Edison achieved its BQDM goals for less than the original budgeted amount and is seeking to utilize additional distributed energy resources with the savings.

Con Edison's proposed solution includes approximately 52 MW of non-traditional utility upgrades, often referred to as "non-wire alternatives." The 52 MW of non-wire alternatives would include approximately 41 MW of customer-side DERs and 11 MW of DERs directly tied to the utility distribution grid.[265] Con Edison has reported that approximately $150 million (75% of the BQDM budget) will go to customer-side solutions while the remaining $50 million (25% of the budget) will go to measures on the utility side.

Figure 16-1 shows a possible DER portfolio in the BQDM Program, including distributed solar, distributed energy battery storage, demand response, energy efficiency, voltage optimization programs, and other resources. Con Edison's local distribution grid demand typically peaks in the evening, requiring a mix of DERs capable of providing more than 50 MW of grid relief during the requisite hours, which the analysis showed was available during the evening peak, as illustrated in Figure 16-1.

One of the first projects Con Edison undertook as it rolled out the BQDM Program was holding a new demand response resource auction for commercial customers in lieu of a pre-existing commercial program. The BQDM demand response program was designed to offer load relief for up to four hours during the peak season for the BQDM area. Con Edison reports that more than half of the winning bidders proposed new technologies such as battery energy storage, whereas historical demand response requirements had typically been met by curtailment or on-site generation.

First results: Steep cost reductions can be realized

The Con Edison NY REV project demonstrates the importance of piloting the use of a broad mix of DERs and other non-wire alternatives to offset traditional utility capital expenditures. Con Edison estimated that an investment of approximately US$ 1 billion would be needed for grid expansion under a business as usual (BAU) scenario. The alternative program at approximately US$ 200 million, which is 80% less than BAU, is anticipated to defer the need for traditional grid expansion investments by several years. Con Edison has devoted resources to develop business models that depart from the traditional model of wire and substation build-out, resulting in the successful reduction, delay, or elimination of expensive grid infrastructure upgrades.[266]

16.4 Integrating renewable energy in the German distribution grid

The German distribution grid is an important factor for a successful energy transition. Approximately 98% of all RE sources are connected to the distribution grid. The highest amount of RE plants are connected to the low-voltage grid, typically around 400 V. The bulk portion of these plants are small PV plants which collectively amount to more than 16 GW of installed capacity. Most of the installed RE plants—25 GW, especially wind turbines —are connected to the medium voltage level. Only a few plants with a capacity of approximately 10 GW are connected to the high voltage level, defined in Germany as 110 kV.[267]

In the past, electricity in the German electricity grid was transported one-directionally from the highest voltage level (transmission grid) to the high, middle and low voltage level distribution grid. Due to increasing RE generation on the middle and low voltage level, electricity already flows from these voltage levels into the transmission grid level during various hours per year. This trend is expected to continue to increase. Similarly, there are also effects from the transmission level to the distribution level – for example, in case of bottlenecks. The TSOs have a defined protocol of counter-measures to address these bottlenecks. The very last of these measures is the curtailment of RE. Since most RE connects on the distribution grid level, DSOs are involved into that process.[268]

The above situation shows that both the tasks and the requirements of transmission and distribution grids are changing due to increasing electricity generation of RE. This leads to necessary changes in the electricity grid, described in further detail in the following section.[269]

Structure and challenges in the German distribution grid

The low voltage, medium voltage and high voltage grids in Germany are operated by about 888 distribution system operators (DSO). These grids supply electricity to over 49 million end consumers, of which approximately 46 million are household customers and the remainder mostly industry and commercial customers. The low-, medium-, and high voltage grids are part of the German distributions grids. Germany has approximately 95,000 km of high-voltage networks (110 kV), most of which are overhead lines. The 4,500 German medium voltage grids (1-30 kV) comprise a total line length of around 510,000 km, and the German low voltage networks 230-400 V) have a total line length of approximately 1.1 million km.[270] Due to differences in structure, voltage and circuit length, the control concepts from the highest voltage levels (220 kV and 380 kV) are not transferable to the distribution grid and different solution for the different voltage-levels are required. There are also different supply situations in rural and urban areas and different penetration levels with RE that require specific local solutions.

How improving voltage control helps to pave the way for RE

Due to the ongoing expansion of RE, the need of distribution grid operators to integrate RE through active operational measures is growing. This leads to an increasing importance of observability and controllability in the distribution grid. In order to avoid bottlenecks and limit value violations, the DSOs control the electricity feed-in of RE as part of grid safety management. Due to the increase of RE capacity in distribution grids, the system increasingly needs flexibility options such as storage or demand side management. Additionally, new concepts and equipment for measuring and controlling the distribution grids are needed.

Reactive Power

With regard to the security and reliability of the electricity system, the stability and the level of the grid voltage must be guaranteed both in normal operation and in the event of failures. The objectives of voltage control are, first, maintenance of the voltage in a permitted range and second, restrictions of the voltage drop in the event of a short circuit. This can be done with the provision of reactive power, voltage-related re-dispatch, voltage-related load shedding, the provision of short-circuit power, and voltage regulation.[271]

Nearly all over Europe, voltage control is part of the ancillary services system. However, the provision of voltage control is organized differently by each country. In Germany and most other countries, voltage control has to be provided as a mandatory service. This means that all power plants connected to the grid are obligated to provide voltage control.

Reactive power is provided differently in the respective national grids. Generators are able and allowed to provide reactive power in all countries, whereas the provision of reactive power by industrial consumers, wind farm producers, and PV systems is not yet universally possible.[272] In Germany, reactive power is provided by conventional power plants, RE power plants, and grid operators. Operators of wind turbines and large solar systems are obligated to reserve part of their capacity for reactive power provision.

With increasing RE deployment, increasing transport distances and power transits in Europe, the demand for voltage control increases. An alternative solution to the current provision of reactive power in the power supply system via conventional power plants will be required. This includes the installation of additional reactive power compensators, inverter stations, reactive power provision by distributed generators and the modification of deactivated power plant equipment for phase shift operation.[273]

Voltage measurement and control

For a stable electricity system, it is important to keep voltage within a certain range. There are several technological options how this can be done: The observability and controllability in the distribution grid differ significantly depending on the voltage level. The operators of high-voltage grids usually have control technologies installed, which collect measurement information and transmit control signals. Capacities in the medium and low voltage grids in the past have been dimensioned very conservatively with the intent that no control intervention is necessary, even at maximum load. Accordingly, the level of observability and controllability is currently very low at medium and low voltage level. State-of-the-art measurement control equipment is used mainly at the substations between medium and low voltage to control voltage fluctuations. The main equipment items in use are as follows:

- Wide-range controllers (medium voltage)
- Medium voltage regulators (medium voltage)
- Adjustable local transformers (medium / low voltage)
- Probabilistic control concepts (medium / low voltage)

Wide-range controllers

In wide-range voltage regulation, the step control of transformers in substations between high and medium voltage is optimized with the help of voltage measurements in the medium-voltage grid. By using wide-range controllers, the voltage in the medium-voltage grid is not measured only at the substation itself, but at several distributed measuring points in the medium-voltage grid. This leads to a better monitoring and control of the voltage situation because more data about the current situation is available and a more precise analysis can be conducted. Voltage fluctuations in the distribution grid can be reduced up to 30 percent by this measure.[274]

Medium voltage regulators

Medium voltage regulators are used to influence the voltage level within a desired control range. Unlike adjustable transformers (see below) which are used in substations, medium-voltage regulators are installed in medium voltage lines. By enabling voltage regulation at medium voltage level, it is possible to connect more decentralized RE. In many cases, the limiting factor for the connection of decentralized RE is not the transmission capacity of the line itself but the risk of non-compliance with the permissible voltage band.

This applies especially to rural areas, where medium-voltage regulators can be used as an alternative to the expansion of the distribution grid.

Adjustable local transformers

In contrast to standard transformers, adjustable local transformers have no rigid transmission ratio between the medium voltage and low-voltage grid. The voltage levels can be decoupled through a dynamic adjustment of the transmission ratio allowing to connect more RE and loads to the same line without grid extensions. The voltage at the low voltage winding can be kept constantly within the permissible voltage band. This leads to a higher available voltage range, both for the connection of more decentralized RE as for connecting additional loads. To realize the observability of adjustable transformers different configurations are possible:[275]

1. The voltage can be measured directly on the low voltage busbar and can be controlled with the help of the tap position changer. In this case an IT connection is usually not realized.
2. A corresponding sensor on one or more selected network nodes can be installed to regulate the voltage at a remote node.
3. All measured voltage values are transmitted to a control centre. Due to the central merging of the data it is possible to optimize the operation of multiple adjustable transformers, but this is more costly, because it requires more communication channels.

Probabilistic control concepts

In Germany, more and smaller generation plants are connected at the medium and low voltage level compared to the extra high and high voltage level. Around 474 conventional power plants blocks are connected to the extra high and high voltage grid. While the number of installed PV systems exceeded 1.6 million already at the end of 2017.[276] Accordingly, the meaning of one single generation plant for grid stability is usually lower at medium / low voltage. However, it is important that at any time a sufficient number of generation plants can be controlled.

Probabilistic control concepts make use of this fact and take the failure of a system component into account when a control signal is transmitted. By applying probabilistic control concepts, it is feasible to soften the requirement that every plant needs a functioning communication link at any time. This entails large cost efficiency potentials because redundancies and back-ups can be reduced. However, it depends on the specific setup of the distribution grid to decide if and which probabilistic control concepts can be applied.

16.5 Need for action in distribution grids all over the world

There are similar challenges for the future design and operation of distribution grids in China, the U.S., and Germany. At the same time, there are different approaches and ongoing pilot projects and tests how to deal with these issues. An exchange of experiences and lessons learned between DSOs, regulators and analysts of the different countries could provide beneficial insights for all parties.

- Parts of the distribution grid in the U.S. need significant expansion, and the cost of this expansion needs to be optimized. The example of New York shows options to reduce costs of distribution grid expansion. Alternative technological solutions and market design concepts can be used to increase cost efficiency.
- The German distribution grid shows increasing situations in which electricity is fed to the transmission grid from the distribution grid level. This can lead to problems with voltage control in the distribution grid. Options to cover this problem are grid extension or the increase of observability ad controllability in the distribution grid. Voltage measurement and control options can be important measures to ensure system stability of the electricity grid. Several technologies are available to do this.
- At the moment there is an ongoing discussion in Germany whether the provision of reactive power should be organised in a more market-oriented way or in combination with regulatory technical obligations for generators. The challenge is to find the right balance between regulatory requirements which might lead to rather high cost inefficiencies and a market-oriented approach which could entail higher cost efficiency but the risk of insufficient availability of reactive power.[277] Several approaches to provide reactive power should be conceptualized, analysed and discussed in detail.

The existing and upcoming challenges of distribution grids need addressing because of their central role in the further realization of the energy transformation. When the share of RE in energy systems increases, the stability and RE intake capacity of distribution grids are a critical path towards successful RE integration. An important next step on that path is to include loads and generators connected to the distribution grid level into the management of frequency control. Availability and specific market/dispatch design of ancillary services for stabilizing assume greater importance for all voltage levels. In Germany an increasing share of technologies providing balancing power for frequency control are connected to the distribution grid. Due to excessively high security requirements or inflexible procedures of DSOs may lead to a lower potential of balancing power from generators connected to distribution grid level. How voltage and frequency control are provided, by which technology, and according to which procedures and regulation are important topics for China as well.

17 Offshore wind

17.1 Summary

China has ample offshore wind potential but offshore wind development has lagged onshore wind and solar growth for several years. China's offshore wind projects have shown lower output than projected given available wind resources, and China's process for selecting offshore wind sites and project developers appears cumbersome and lacking in transparency. These failings have helped drive up the price of electricity from offshore wind, further slowing the development of this resource.

This chapter draws on international experience, particularly in Denmark, to present various suggestions on how to improve on the present pattern of offshore wind development in China, including the following:

- Carry out a thorough screening before designating areas for offshore wind, accounting for wind conditions, sea depths, grid connection options, seabed conditions, and marine life. Regulators should then rank the potential projects based on expected economic performance given these conditions and limitations.
- Developers should have greater flexibility to design the wind farm and choose foundations, turbines and other components, without local content requirements that can prevent innovation or restrict price competition for components and services.
- Involve all affected parties with interests at sea at government level already at the beginning of planning to avoid future conflicting interests. Consider clarifying competing interests such as shipping routes, environmentally sensitive sites, fishing areas, resources and extraction up front in planning.
- Finally, employ existing studies on environmental impacts in the public domain before requiring expensive and time-consuming analysis. If no such resources are available, set up a general framework for EIAs and ensure their results are public for the benefit of future offshore wind planning.

17.2 Development of offshore wind a high priority towards 2020

China has natural advantages to develop offshore wind with a significant amount of coastline and sea areas. The technical potential for offshore wind in China is estimated to be approximately 200 GW (below 25 m water depth) and 500 GW (below 50 m water depth).

In addition, there are abundant wind resources near the coast. Deployment of off-shore wind has been high on the energy policy agenda since the formulation of the 12th five-year plan, which had a goal of 5 GW offshore wind in 2015. However, the deployment has been slower than expected with major challenges in the practical implementation, and by the end of 2017, the cumulative installed capacity of offshore wind in China only amounted to 2.79 GW[278].

In the 13th Five-year plan the capacity goal for 2020 is 5 GW offshore wind in 2020, and NEA has the accelerated deployment of offshore wind as a high-priority task in the coming years. The national goal is divided on a province level as shown in Table 17-1:

Table 17-1: Status of offshore wind capacity per province

Province	Target for 2020 [MW]	Under Construction [MW]	Approved Potential [MW]
Tianjin	100	200	-
Liaoning	2	100	1900
Hebei	1.5	500	5600
Jiangsu	3000	4500	16000
Zhejiang	300	1000	6470
Shanghai	300	400	6150
Fujian	900	2000	13300
Guangdong	300	1000	12000
Hainan	100	350	3950
Total	**5003.5**	**10050**	**65370**

Four provinces along the southeast coast: Jiangsu, Fujian, Guangdong and Zhejiang; have been selected as key provinces to develop offshore wind power according to 13th FYP for Wind Power Development.

Jiangsu

It is the province with the highest current offshore capacity. By the end of 2016, it had 1.1 GW of grid-connected capacity, representing a 39.4% of the total 2.79 MW installed in China. Onshore curtailment drove interest in offshore development in the region to achieve internal targets. First mover experience with offshore means value chains and best practices are in place, possibly for some time producing lower costs for future development than in other provinces. According to the 13th FYP for Wind Development, by 2020, the target for the provincial cumulative grid-connected offshore wind is 3 GW, and the scale of under –construction will reach 4.5 GW. Jiangsu presents a comparatively shallow water depth, with a much less steep increase in depth offshore. This presents advantages for installation costs of wind turbines. However, the relatively low wind speeds in Jiangsu mean moderate utilisation rates.

Zhejiang

Zhejiang currently has a 252 MW offshore wind project (Guodian Zhoushan Putuo NO.6) under development. While it has reasonably abundant wind resources, there are certain conditions (high tides, strong currents, extreme weather events such as typhoons) that introduce challenges. Extreme weather events limit the windows of time available for construction and maintenance work, whereas currents and tides require higher quality turbines, able to resist them. The local government is highly supportive of further offshore projects. According to the 13th FYP for Wind Development, by 2020, the provincial target for the cumulative grid-connected offshore wind is 300 MW with further 1 GW under construction.

Fujian

While less advanced than Jiangsu, it also is in the process of developing offshore wind. By the end of 2016, the grid-connected installed capacity was 67 MW. This province has the most abundant offshore wind energy resources. Both component and wind turbine suppliers have established facilities in the local offshore wind industry park, created by China Three Gorges and the Fujian government. The creation of these facilities establishes a clear production and value chain in the area. There is a pilot project (Fuqing Xinghua Bay) in development (where the first units have been already connected and generating electricity) which will provide construction and operation experience for later projects. This is the first wind project with turbines of 5MW or more. According to the 13th FYP for Wind Development, by 2020, the provincial target for the cumulative grid-connected offshore wind is 900 MW and an additional 2 GW under construction.

Guangdong

Similarly to Zhejiang, this province has a 102 MW offshore wind project (Zhuhai Guishan) that recently finished construction on May 14th 2018. Furthermore, it presents similar wind resource availability, and weather conditions, providing challenges in regards to construction and resilience. The provincial government is working on developing a local offshore industry park (as done in Fujian), and streamlining the approval process for new projects. According to the 13th FYP for Wind Development, by 2020, the provincial target for cumulative grid-connected offshore wind is 300 MW, with an additional 1 GW under construction.

17.3 High costs and high risk are the main challenges for off-shore wind

When analysing success in the expansion of the offshore wind sector in China, the achievement of the previously presented targets is one of the main criteria. Nonetheless, the way in which these targets are attained, the costs associated with achieving them, as well as the correct functioning of the power system in the future, are all factors to account for.

A relevant measure of cost is the Levelised-Cost-of-Energy (LCOE), which gives a measure of the relationship between the energy produced by a project, and the costs necessary to build and operate it. With the recent announcement from NEA indicating a shift towards an auction-based system, low LCOE should be one of the factors that could be reflected in the bid level. Projects with lower LCoE also require less public support, since they present a stronger business case and require lower compensation to be profitable.

When considering the LCOE for offshore wind projects, one of the main drivers is the performance of the project, measured as capacity factor/utilisation rate or full load hours. Two projects with identical capital and operational costs can present significantly different LCOE levels if they have different full load hours; and while technology choice and other design decisions can affect the obtained full load hours of a project, the main deciding factor will be the wind resource, and therefore the choice of site. Good wind resource leads to high full load hours that give wind turbines higher overall power production with a unit of investment, which may drive down the LCOE significantly. For this reason, being able to site offshore wind projects in areas with high wind resource availability will enable to lower the LCOE for future projects significantly. It is important to remember that China presents average wind resources, with several areas presenting low wind speeds.

At the time of writing, the full load hours achieved by existing offshore wind projects has been suboptimal, with values well below what has been seen in other areas of the world with similar wind resource availability. As seen in Table 17-2, many of these projects present less than 3000 full load hours per year. The existing process for selecting sites to be developed is particular for each local area, with complex decision processes and actors, and with a general lack of transparency in regard to the criteria used for defining the sites. The complexity and lack of transparency is a roadblock towards ensuring that the best wind resource sites are the ones to be developed first. Achieving increased full load hours for future projects will be one of the main issues to tackle while attempting to lower LCOE for offshore wind in China, and the site selection process will definitely be an area upon where to improve.

Table 17-2: Chinese offshore wind projects performance data[279]

Province	Project Name	Capacity (MW）	Annual Full-load hours (h)	Annual Energy Production (GWh)
Jiangsu	Huaneng Guanyun	300	2388	716.4
	Jiangsu Rudong Huangshayang H1	200	2798	559.6
Guangdong	Yangjiang Shaba	300	2615	784.5
	State Power Investment Shenquan	400	3174	1269.6
Zhejiang	Zhoushan Putuo #6	250	2444	611
	Daishan 4#	300	2498	749.4
Fujian	Putian Pinghai	50	3175	158.75
Liaoning	Dalian Zhuanghe	300	2544	763.2

Besides full load hours and project performance, there is another central element that needs to be addressed for China to achieve its goals in an efficient manner: risk. Perceived risk by developers and investors will be reflected in the final project LCOE, either directly due to increased weighted average cost of capital (WACC) produced by higher demanded internal discount rates, or indirectly due to decreased competition in the auction process due to fewer developers being willing to shoulder the increased risk.

While the sources of risk for an offshore wind project are innumerable, there are several that are possible to be managed, and therefore of high relevance for the Chinese case. The siting and developer allocation process, for example, beyond being able to define a project's capacity factor can also define the level of risk for the developer, as well as the business case due to reduced profits.

Allocating a developer and a site for a project is a long process, with many involved stakeholders. Every stakeholder can have different interests and in many cases contrary ones. If the process is not correctly managed, both in terms of decision transparency and in terms of a clear timeline, the possibilities of a project failing, or changing substantially, well into the project timeline, are increased. If there are possibilities for a project site being rejected, after it has been assigned to a developer, then this uncertainty will be reflected as an increased bid price since the developer will require a higher rate of return in exchange for exposing itself to the risk.

The final challenge faced by China is a common challenge for countries with immature offshore wind sectors: lack of experienced developers and manufacturers with state-of-the-art technologies. Recent projects in China have favoured the utilisation of market-tested turbines designed by SiemensGamesa, instead of more recent high-capacity models. To achieve the proposed targets in an efficient manner, there will be a need to utilise the latest technology available, and consequently, developers and manufacturers will need to gain expertise associated with these technologies. This challenge is further compounded by the relative absence of international developers and manufacturers, who would be able to provide know-how and best practices, as well as proven experience in the utilisation of current technology wind turbines. The lack of international developers does, evidently, also affect the competitiveness of the market. Without competition from these international developers, local Chinese developers will have limited incentives towards bidding competitively and search for a technological advantage.

The targets China has chosen are ambitious and, while reasonable, their fulfilment *in a sustainable way* will require an explicit effort towards addressing the previously presented challenges. Fortunately, many of the challenges are common to the challenges faced by other markets during their developing stages, and there is a possibility for transferring the lessons learned.

17.4 International experience shows reduced costs by using auctions

In 2017 the global offshore wind market grew by approximately 3.3 GW, with most new developments being sited in the UK, Germany, and China. In future years, this level of growth is expected to be maintained or increased.

The increase in grid-connected capacity has, interestingly, occurred despite an increased pressure towards lower costs and increased competition, particularly on the European market. Recent cost developments are represented in the milestone transition towards a support system based in Contracts for Difference (CfD) in the UK, the 49.9 €/MWh bid in the Danish Kriegers Flak 600 MW project, and the recent zero-price bids in Germany.

Northern Europe has decades of experience from auctions for offshore wind. The Danish, German and Dutch auction model share many similarities, which aim to attract competent bidders in an efficient, transparent and "certain to deliver" process. One of the keys to attracting more competent bidders has been to change the risk allocation such that more types of investors become interested. Allocating risks to the parties best able to manage them also proves to be an effective tool to bring down bid prices. Consequently, it is expected that in the next 8 years close to 30 GW of grid-connected capacity will be added to the UK, German and Dutch markets.

Outside of Europe, most of the growth has occurred in Asia Pacific, with China leading the way in total grid-connected capacity installed. Recent targets for renewables in South Korea as well as the planned phase-out of nuclear energy foreshadow a significant development of offshore wind. The American region has presented limited growth, with a pilot 30 MW project in the United States. Nonetheless, there are expectations of strong growth in the region, supported by a redefinition of the policy framework for the sector.

As the offshore wind sector and technology mature, countries in Europe have transitioned towards auction-based systems. Under a typical auction system, possible developers bid the level of the support scheme (often a feed-in tariff or feed in premium) they need for carrying out a project, and the developer with the lowest bid is awarded the project. In this way, there is competition across developers for reducing their costs, and an incentive for lowering the LCOE of projects.

There are several design elements that can vary on the design of an auction, but the focus points with the highest impact on risk and LCOE are:

1. Award criteria & prequalification: Prequalifying developers in terms of technical experience and financial capability ensures that high-quality developers will participate. This can also be considered as one of the criteria for awarding a tender.
2. Energy targets and pipeline visibility: Having a clear roadmap for the development of offshore wind, including future auctions, reduces the risk for developers and enables synergies.
3. Timeline of the auction: A short time between the awarding of the auction and the beginning of construction, like in Denmark, allows for reduced risk of developers. On

the other hand, longer time between the decision of auctioning and the final bids allows for carrying out preliminary studies.

4. Penalties and fees: It is necessary to have penalties and fees that are high enough to ensure compliance from developers and avoid delays and cancellations, while at the same time they have to be low enough to ensure broad participation in the auction.
5. Reference price: If the awarded subsidy is a premium, it is necessary to clarify what the reference price will be. A clear understanding of the reference price and expected evolution will limit uncertainty for developer bids. Furthermore, the level of exposure to market prices (hourly, monthly, annual, or none) will affect the price signals received by developers.
6. Duration and stability of the subsidy: A clear timeline and duration of the subsidy will allow for developers to bid with increased knowledge. Possible changes in the subsidy in the future, like a renegotiation clause, will demand much higher risks from developers, which will be reflected in the level of the bids.
7. Scope: A clear understanding of the responsibilities and scope of the whole project, including grid connection, for example, is necessary. Furthermore, it is important to ensure that there are no perverse incentives in terms of ownership of connection infrastructure.
8. Off-taker bankability: The government has the possibility of backing the energy off-takers to improve their bankability. Such backing might improve the bankability rating of the off-taker, and therefore the confidence financial institutions have on the project.

A comparison of the main design elements of offshore wind auctions in Denmark, United Kingdom, Netherlands and Germany is shown in Table 17-3 below:

Table 17-3: Comparison of offshore wind subsidies and risk[280]

Country	Denmark	Belgium	Netherlands	Germany	United Kingdom	France
Subsidy Scheme	Feed-in premium	Feed-in premium	Feed-in premium	Feed-in premium	Feed-in premium	Feed-in tariff
Risk for investors	Lowest	Some	Some	Limited	Lowest	Lowest
Comments	-No price cap - Hourly electricity price as reference	-No price cap - Annual electricity price as reference	-Price cap -Annual electricity price as reference	-No price cap - Monthly electricity price as reference	-No price cap - Hourly electricity price as reference	-No price cap - No exposure to market prices

As a consequence of these decisions, auctions in each country will have different results, process times, prices, and risk perceptions. Particularly, the study on subsidy schemes and tax regimes carried out by TKI Wind op Zee in 2015 shows that the approach pioneered by Denmark and also currently used in The Netherlands provides a minimised risk for developers. This has been reflected on the extremely competitive prices that recent projects have achieved, as well as the straightforward development process for the auction of Kriegers Flak, the next wind farm to be commissioned in Denmark in 2021.

Table 17-4: Lifetime offshore capacity factors comparison

Country	Lifetime Capacity Factor
Denmark	41.9%*
Germany	41.1%*
United Kingdom	37.8%*
Belgium	36.1%*
China	32.4%**

**: Analysis from EnergyNumbers*
***: Data from CREEI*

Table 17-4 shows that the capacity factor of Chinese offshore wind farms is well below the capacity factor resented by European offshore wind farms. Even when we consider the capacity factor of wind farm projects situated in Fujian, a province with wind conditions comparable to high wind sites in Europe, we can see that the performance in terms of full load hours is significantly below Danish and German performances.

This difference between capacity factors indicates that the performance of a wind turbine is not solely defined by the available wind resources. In effect, full-load-hours are considered a result of design decisions taken during the planning and design phases of a new wind project. The selection of an adequate auction format, the solidity of the spatial planning and site selection process, as well as the level of interaction with developers when defining the relevant areas for the project, are all elements that will affect the final performance of a project.

Particularly, a solid spatial planning framework will allow developing projects in the areas that present the most favourable wind micro-conditions, and therefore allow for high capacity factor wind farms. A clear understanding of maritime-use limitations, as well as the overlaid requirements by different authorities and stakeholders, will also minimise the risk of a project being stopped or delayed due to complaints or conflict in regards to the siting. On the other hand, allowing developers to participate early and continuously in the determination of the specific areas of the site to be developed, allows for a better understanding of the requirements of the associated technologies used and the needs of the developers themselves. Together, a solid spatial planning framework and strong interaction with developers during the site allocation process have the possibility of optimising the performance of the projects to be carried out. The possibility of letting developers themselves optimise the micro-siting and technology choices of each project allows for more flexibility in their design and therefore lower bid prices.

From an economic perspective, the performance of the wind farm will have a direct impact on the feasibility and attractiveness of the project. Since the cost of an offshore wind farm is dominated by the capital expenses, an increased performance implies a higher amount of energy produced at the cost of an almost negligible increase in operating expenses. It is easily seen that this relation directly produces a decrease in the project's Levelized-Cost-of-Energy. Higher capacity factors will, as well, decrease the balancing costs associated with variable generation.

Table 17-5 shows the results of a quick sensitivity analysis on LCOE carried out for a referential offshore wind project. An increase of 10% capacity factor (close to 900 full load hours per year) produces a decrease of more than 20% in the LCOE.

Table 17-5: Effect of Full-load hours in LCOE

Full Load Hours	3.066	3.504	3.942
Capacity Factor	35%	40%	45%
LCOE [RMB/kWh]	632	553	491

It is interesting to note, that the high impact of the full-load hours on LCOE makes the selection of technology paramount. In areas with lower wind speeds, it may very well be worth considering utilising turbines with large swept areas, but smaller sized generators, which allow for better use of the wind resource at lower wind speeds.

On the other hand, the decrease in risk produced by a clear and optimised spatial planning and site selection process will also be reflected on the economic parameters of the project. As the risk of an auction-awarded project having to be cancelled or delayed decreases, the required rate of return of the project investors will also be relaxed. Projects with high risk will require greater risk premiums than projects where the risk is limited, and this will be reflected on the bid price, as well as the LCOE (typically through the cost of capital calculation).

17.5 Improvement of offshore wind development in China

We can draw experience from the transition of the regulatory framework to a mature system in Europe, to inspire solutions for the challenges that the offshore wind sector faces. These suggestions, though, have to be understood not as a proposed transferral of mechanisms, but as an indication of the direction and principles that govern these regulatory approaches.

As discussed previously, a stark difference between the European approach and the Chinese approach in regard to the regulatory framework for the development of offshore wind is the emphasis and distribution on risks. In mature European markets, the spatial planning [preplanning process] design, as well as the decision of which government agencies are the entry point for authorisation and permitting, has been carried out with an emphasis on de-risking developments. In China, this emphasis is not visible.

When we look at the preplanning process of a country like Denmark, we can see that a significant amount of preliminary investigations are carried out by government agencies and well before a developer is selected. The selection of the geographical sites available for development of offshore wind energy, for example, is carried out by the Danish Energy Agency via a spatial planning approach that does not only consider the different interests of varied stakeholders (such as environmental agencies, military, etc.), but also the wind resource and geographic characteristics of the sites, and therefore their economic attractiveness. As such, by the time a project auction is carried out, there is a clear understanding that the site is economically attractive, as well as accepted by all relevant authorities and agencies. This spatial planning approach minimises the risk for developers and enables them to access high wind resource areas, therefore promoting competitive low-cost bids.

Another de-risking element of the Danish preplanning process is related to the environmental impact assessment, as well as preliminary geophysical, met-ocean, and unexploded ordinance studies. These studies are vital for understanding the feasibility of an offshore wind project, as well as the technical possibilities for the development of the site. Under the Danish offshore wind development framework, these studies are carried out before the auctions under the guidance of Energinet, the Danish Transmission System Operator (TSO). The scope and content of these studies are, furthermore, discussed with interested developers as to maximise the relevance and utility of the results, i.e. ensuring that a relevant *Rochdale Envelope*[281] is created. In this way, by the time the auction process is carried out, bidders have an increased amount of information regarding the proposed site. In this case, the risk of finding unsuitable conditions (such as seabed, or marine fauna) is significantly minimised for developers. If the Rochdale Envelope is wide enough, it allows for developers to optimise themselves the micro-siting and technology choice, increasing their possibilities for competitive bids. It is relevant to note that while the study is carried out by the Danish TSO, the costs are later reimbursed by the winner of the auction process. All in all, this approach enables developers to consider smaller risk premiums in their bids, due to their diminished exposure.

The spatial analysis carried out by the Danish Energy Agency is supported by the single point of entry approach to offshore wind development, also called the One-Stop-Shop. Under this system, the Danish Energy Agency acts as the only contact point for developers and takes charge of interfacing with all other relevant stakeholders. This not only allows compiling restrictions and preferences for spatial planning from all relevant actors but at the same time simplifies the whole process for developers. Developers, instead of having several parallel processes for permitting and authorisation, are able to carry out a single, fast-track process that drives all associated permits.

While a single entry approach, like the One-Stop-Shop, requires extensive reworking of the inter-agency dynamics, it is important to underline the driving principle under it: to maximise coordination and cooperation across agencies. Under this understanding, it can be valuable for China to implement policies that follow the same rationale. A first step would be to try to involve all relevant government actors as early in the process as possible and in this way try to find objections towards a proposed site before extensive studies are done. Furthermore, while having a single point of entry might be unachievable in the short term, it is possible that a number of agencies could cooperate closer together, and in that way minimise the points of entry for possible developers.

17.6 Recommendations for offshore wind deployment in China

With the potential for offshore wind of 200-500 GW, China would benefit from developing a strong long-term sustainable framework for the development and deployment of offshore wind capacity far beyond the 2020 targets. Based on the international experiences from more mature offshore wind markets, and looking at the specific Chinese context the following recommendations in order of impact would be relevant to consider for the Chinese central and local government:

- Carry out a thorough screening and planning before designating areas for offshore wind turbines.
- Take wind conditions, sea depths, grid connection options, seabed conditions, marine life etc. into consideration when screening for suitable sites for offshore wind farms, and rank the projects based on expected economic performance (LCOE)
- Full flexibility to design the wind farm and choose foundations, turbines and other components. No requirements for local content of the project.
- Involve all affected parties with interests at sea at government level already at the beginning of the planning procedure. This will create interest in a commitment to the process as well as to the sites chosen.
- Consult all relevant authorities with interests at sea, in order to avoid future conflicting interests. In this way, restrictions can be identified early in the timeline.
- Consider also to clarify competing interests such as shipping routes, environmentally sensitive sites, fishing areas, resources and extraction up front in the planning.
- Consult with evidence from effect studies on environmental impacts already assessed and accessible in the public domain before requiring expensive and time-consuming analysis as part of the EIA requirements.
- If not in place, consider setting up a general framework for environmental impact assessments (EIAs).

Annex: China Energy System Model Review

Annex: China Energy System Model Review

Introduction

There is a global change under way impacting the way people around the world access, consume, and experience energy. Many countries around the world are transforming and modernizing their energy systems to be more efficient, reliable, low-carbon, and resilient. Energy system assets are not only capital-intensive and long-lasting, but also vital to the social and economic activities of each country. Therefore, decisions about the energy system need to be informed by robust modelling and analysis. Energy system modelling is a key tool for informing these decisions.

Energy system models are computational models that simulate how energy is produced, transformed, and consumed considering socioeconomic behaviours and physical constraints. These models generate insights regarding a range of issues, including energy supply and demand, climate change mitigation pathways, and the impacts of energy, environmental, and economic policies. [282]

Modelling the energy system is difficult because of the immense complexity of system components and economywide interlinkages between sectors and consumer and producer behaviour. For the power sector, this is further complicated by the need to balance electricity supply and demand instantaneously and the requirement for physical transmission lines to move electricity. [283] In recent years, the development of variable renewable energy, distributed energy, electrification, and flexible demand has brought additional challenges to modelling efforts. Energy system modelling today needs to address issues with time and spatial resolution, uncertainties, and complexities involving both the physical system and human behaviour. [284] In long-term decadal modelling in particular, assumptions about political decisions, economic incentives, and social behaviour could have tremendous impact on the results, but they are difficult to predict in the modelling exercise. [285] Scenario analysis is often conducted in cases of great uncertainty regarding some of these assumptions.

CREO leverages the China Renewable Energy Analysis Model hybrid energy system model to provide analysis specific to the needs of the Chinese system. The Electricity and District Heating Optimization Model (CREAM-EDO) optimizes investments and operations for electricity and district heating for provinces and directly administered municipalities with consideration for a diverse suite of technologies. CREAM-DEMAND uses the Long Term Energy Alternatives Planning System (LEAP) framework to provide detailed sector specific end use energy projections. And CREAM-CGE analyse the macroeconomic trends for China's energy transition.

This chapter is divided into three parts: 1) a brief history of energy system models in China, with a list of the primary models currently in use; and 2) a comparison between China Renewable Energy Outlook (CREO) 2017 results and World Energy Outlook (WEO) 2017

China results; and 3) a summary of the main similarities and differences between CREO and WEO results as well as conclusions for future modelling work.

Energy System Models in China

A variety of economic models have been developed in China over the past three decades, but sophisticated energy system-specific models are relatively few and recent.

The earliest energy system models in China were developed in the early 1980s, most of which are simple input-output models. [286] They contributed to energy demand forecasts for China and certain regions but were not highly regarded due to the traditional administrative-planning dominated practices. [287]

It was not until the 1990s that more advanced energy system models started to be developed in China. The Institute of Nuclear and New Energy Technology (INET) at Tsinghua University used an input-output model coupled with the INET model for climate change mitigation pathway studies in 1994. [288] In 1997, the State Council Development and Research Institute, in collaboration with the Development Centre of the Organisation for Economic Co-operation and Development (OECD), developed China's first computable general equilibrium (CGE) model. [289] In 1999, the Institute of Quantitative and Technical Economics of the Chinese Academy of Social Sciences also developed a CGE model in collaboration with Monash University, and the Energy Research Institute of the State Planning Commission started building the Integrated Policy Assessment Model for China (IPAC) in collaboration with Japan's National Institute for Environmental Studies, based on the Asian-Pacific Integrated Model. [290]

In the 2000s, modelling practices started to blossom in China. A MARKAL-China model was developed by a research team from Tsinghua University in 2001 and has since then been adopted and incorporated into the energy system planning of several regions, including Beijing and Shanghai. [291] In 2004, the same Tsinghua team integrated the top-down MACRO model with the bottom-up MARKAL model to create a MARKAL-MACRO China model for the study of carbon mitigation strategies and their impact on the energy system, and Shanghai University of Finance and Economics built an energy-economy-environment (3E) model for the analysis of "green GDP" in Shanghai's industrial sector.[292]

The main energy system models currently used for analysing China's energy system and the key studies they support are summarized below. This is by no means a comprehensive list; many models in China, such as those used by China Electric Power Research Institute and State Grid Economic and Technological Research Institute, are highly confidential, and no public documentation or studies are available. Other models are used in academic settings and have not been widely applied for decision-making.

Table 18-1. Primary Energy System Models Currently Used in China

Model	Full name	Type	Geographic Resolution	Planning Horizon	Primary User	Used in/ Publication
MRIO	multiregional input output model	top-down input/output	regional	short-term	Chinese Academy of Sciences	[293]
EPPEI Planning Model	EPPEI generation planning model	Bottom-up optimization	national	Medium- to long-term	Electric Power Planning & Engineering Institute	
EPS	energy policy solutions/ simulator	system dynamics	national	long-term	National Center for Climate Change Strategy and International Cooperation, NDRC ERI	[294]
IPAC-ERI	integrated policy assessment model	Hybrid	national, regional, provincial	long-term	NDRC ERI	[295]
CREAM (CGE, LEAP, EDO)	China renewable energy analysis model	Hybrid	national	long-term	NDRC ERI/CNREC	[296]
CGE-NCEPU	computable general equilibrium model	top-down CGE	national	short-term	North China Electric Power University	[297]
GCAM-China	global integrated assessment model	market equilibrium	national	long-term	Pacific Northwest National Laboratory	[298]
MSCGE	multisector computable generation equilibrium model	top-down CGE	national	medium-term	State Council Development Research Center	[299]
GESP	generation electricity system planning model	bottom-up optimization	national, regional	medium- to long-term	State Grid Energy Research Institute	[300]
DCGE-SIC	dynamic computable general equilibrium model	top-down CGE	provincial	short-term	State Information Center	[301]

China TIMES	integrated MARKAL-EFOM system model for China	bottom-up optimization	national	long-term	Tsinghua University	[302]
MARKAL-MACRO China	market allocation model and macroeconomic model	Hybrid	national	long-term	Tsinghua University	[303]
Tsinghua-MARKAL	market allocation model	bottom-up optimization	regional	long-term	Tsinghua University	[304]
SWITCH-China	solar and wind energy integrated with transmission and conventional sources - China	bottom-up optimization	national	medium- to long-term	UC Berkeley, Stony Brook University	[305]
MESSAGE	model for energy supply strategy alternatives and their general environmental impact	bottom-up optimization	national	long-term	University of the Chinese Academy of Sciences	[306]

Comparison of CREO 2017 and WEO 2017

This section compares the key results from the CREO 2017 Stated Policy Scenario (SPS) with those of the WEO 2017 New Policies Scenario (NPS), and the key results from the CREO 2017 Below 2 Degree Scenario (B2S) with those of the WEO 2017 Sustainable Development Scenario (SDS). The CREO 2018 results are not used here because WEO 2018 has not been published at the time of writing. The key results include primary energy demand, final energy demand, power sector capacity and generation, and carbon emissions. This section summarizes the key similarities and explains the differences in these results. Because the WEO only goes out to 2040, CREO results up till 2040 are used for comparison, even though the CREO study goes to 2050.

In the first pair of scenarios, the SPS in CREO considered China's existing and announced policies and assumes a continuation of the political will behind these policies. This is analogous to WEO's NPS, which includes existing policies and measures and the likely effects of announced policies, as opposed to WEO's Current Policies Scenario, which only contains implemented policies. In addition, the SPS in CREO is consistent with China's NDC, where the CO_2 emissions peak around 2030 or earlier, the CO_2 emissions per unit of GDP drop 60%–65% from the 2005 level, and the share of non-fossil fuel in primary energy consumption reaches around 20%. Both the B2S and the SDS represent scenarios that are consistent with the goals of the Paris Climate Agreement, which is more ambitious than China's current announced NDC.

Macroeconomic Assumptions

The macroeconomic assumptions between CREO 2017 and WEO 2017 are similar, though the two reports use different metrics and milestone years. CREO 2017 assumes continuous population growth to 1.51 billion in 2030 and then a slight decrease to 1.38 billion in 2050. WEO 2017 assumes a growth rate of negative 0.10% per year to a population of 1.40 billion in 2040.

For the GDP assumption, CREO starts at 60 trillion RMB in 2015 and WEO starts at 67.4 trillion RMB in 2015. CREO assumes an average annual growth rate of 4.80% from 2016 to 2050. WEO assumes an average annual growth rate of 4.50% from 2016 to 2040 (9.20% from 2000 to 2016, 5.80% from 2016 to 2025, 3.70% from 2025 to 2040).

Primary Energy Demand

The total primary energy demand in WEO NPS is larger than that in CREO SPS by about 12.57% in 2040. Noticeably, the total primary energy demand starts to decline in CREO SPS after 2025, whereas WEO NPS shows a continuing growth pattern. This reflects the different macroeconomic assumptions, including shifts in industrial sector energy intensity, between the two studies for these scenarios. Aside from the long-term trajectory, the 2016 primary energy demand in CREO 2017 is 3130 Mtoe and in WEO is 3006 Mtoe. The mismatch in historical data was a result of both studies being based on preliminary 2016 statistics at the time of writing, which could be correct in future versions.

The primary energy demand in CREO B2S is more constrained than in WEO SDS in the near term (2016–2020), and then the two scenarios follow a similar shape. Primary energy demand rises from 2020 to 2025, flattens around 2030, and declines afterward. But if only fossil fuel consumption is compared, the CREO B2S shows a much more dramatic decline in total fossil fuel consumption from now to 2020 due to strict CO_2 emission reduction targets in 2020, whereas in WEO SDS, fossil fuel consumption declines gradually from now to 2025, and after that more aggressive coal reduction is observed than in the near term.

Both CREO and WEO studies give hydropower a moderate projection, reflecting the fact that hydro is highly dependent not only on resource availability but also on policy and environmental factors. In terms of nuclear, CREO has a much lower projection in both scenarios than WEO. Since the Fukushima nuclear disaster, China has started a re-examination of the nation's nuclear policy. China National Renewable Energy Center's (CNREC's) assumption is that new development of nuclear would only be allowed along the coast, and neither scenario assumes any inland nuclear. As a result, CREO SPS and B2S have almost the same amount of nuclear, whereas nuclear plays a more important role in WEO SDS. The bioenergy demand is very similar between CREO SPS and WEO NPS (only a 17 Mtoe difference in 2040); it is 30 Mtoe higher in CREO B2S than in WEO SDS in 2040.

Figure 18-1. Primary energy demand comparison (CREO 2017 SPS and WEO 2017 NPS)

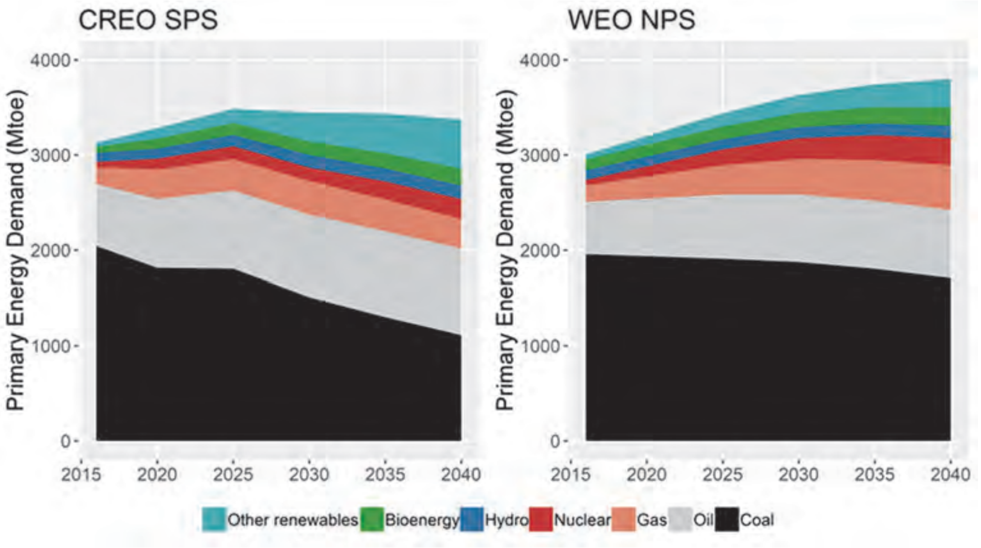
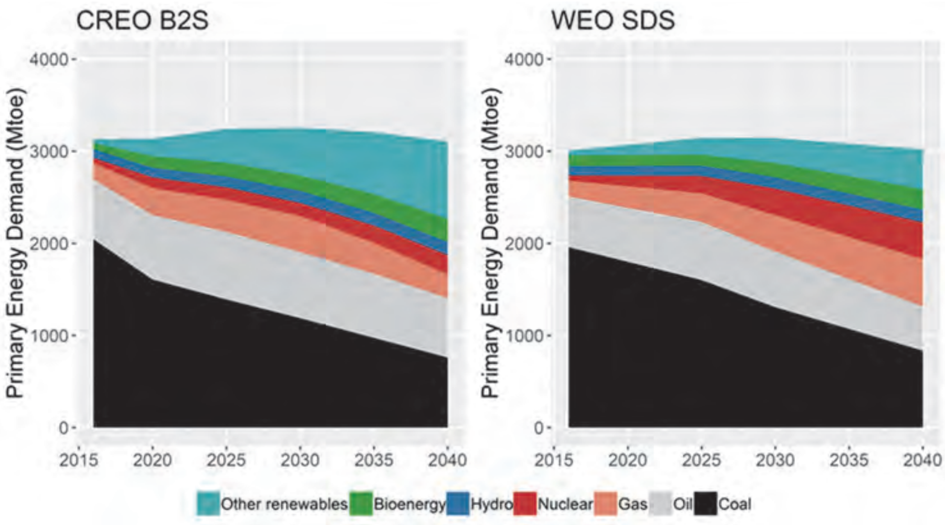


Figure 18-2. Primary energy demand comparison (CREO 2017 B2S and WEO 2017 SDS)



Final Energy Consumption

Unlike primary energy demand, the final energy consumption in CREO SPS shows continuous increases before plateauing at 2035. In WEO NPS, the final energy consumption keeps growing for the entire simulation period. The 2016 final energy consumption is about 325 Mtoe (16.88% higher in CREO SPS than in WEO NPS), reflecting a considerable difference in input data. Another noticeable difference in final energy consumption between the two scenarios is that fossil fuel consumption peaks around 2020–2025 in CREO SPS, whereas it peaks around 2030–2035 in WEO NPS.

As shown in Figure 18-3 and 18-4, the CREO has significantly more final energy consumption in all three fuel categories in 2016. The trends in the CREO B2S and WEO SDS are similar due to energy efficiency. In both studies, coal continue to decrease from 2016 to 2040, oil has an uptake in the near to medium term and gradually decreases to similar levels in 2040 as in 2016. But for gas, CREO B2S estimates a dramatic increase from now to 2030 and then a sharp reduction from 2030 to 2040, while WEO SDS estimates a continued growth. It is unclear whether China will have the gas resource or import to support a significant growth in gas consumption, or whether a sharp decline would be economical due to the rather longevity of gas infrastructure.

The electricity and heat consumption for 2040 is higher in both CREO scenarios than in the WEO scenarios. The higher level of electricity consumption in CREO, especially in the B2S, is related to more aggressive assumptions of electrification of the end-use sectors relative to the WEO. WEO considers increasing demand for space cooling, rising levels of appliance ownership, and additional contribution from a switch from solid fuels and oil to electricity for cooking. As for heat consumption, CREO projects growth from 5.01% in 2016 to 7.96% in 2040 in SPS and to 8.79% in 2040 in B2S. In comparison, heat consumption drops in both WEO scenarios, from 4.60% to 4.05% in NPS and to 4.03% in SDS. This is mainly driven by WEO's assumption for China's building efficiency improvement. Space and water heating represent around two-thirds of China's building energy consumption today, part of which is satisfied by solid fuels in rural China. Based on China's ambitious green buildings target in the 13th Five-Year Plan, WEO assumes a 75% reduction of space heating intensity in new residential buildings in NPS.

Figure 18-3. Final energy consumption comparison (CREO 2017 SPS and WEO 2017 NPS)

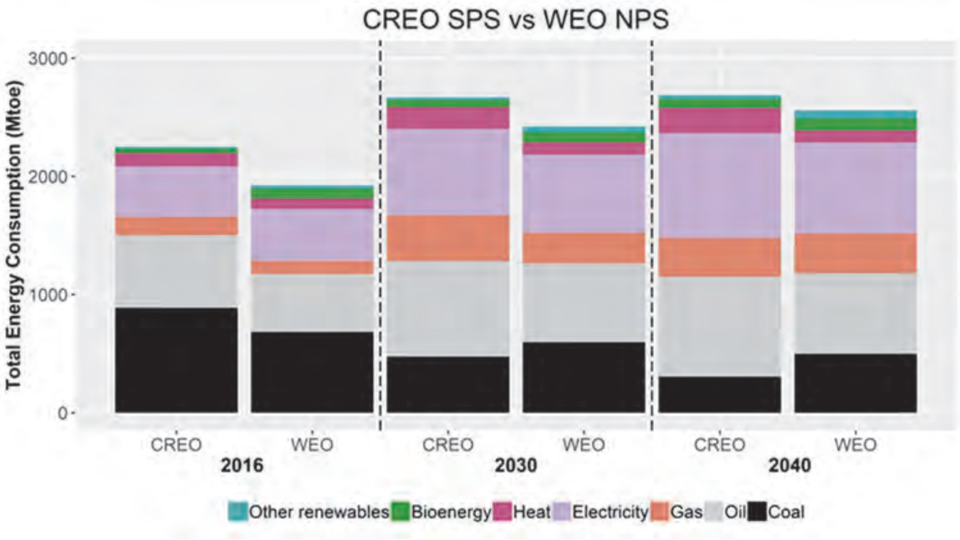
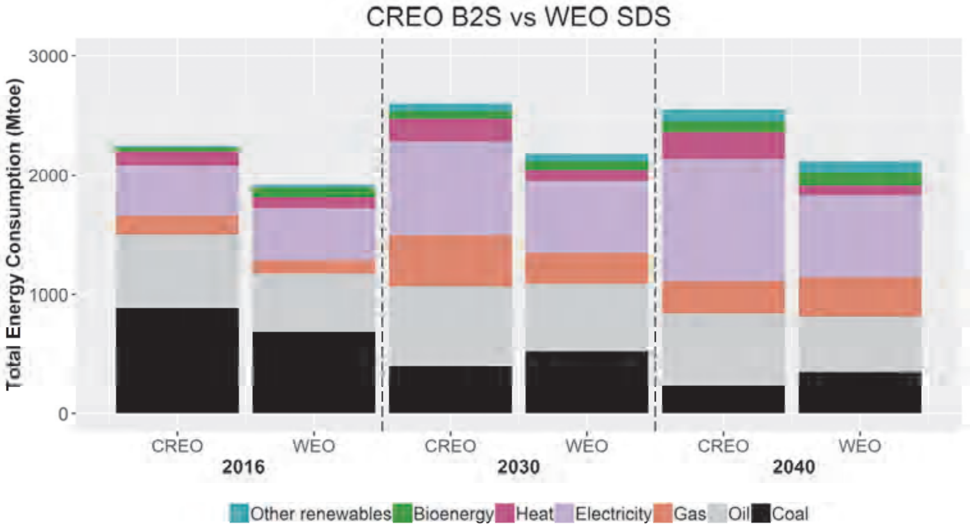


Figure 18-4. Final energy consumption comparison (CREO 2017 B2S and WEO 2017 SDS)



For end use, the industry sector decreases in both CREO scenarios and increases in both WEO scenarios, even though both depict a transition from heavy industries to less energy-intensive industries. The industry sector's energy consumption drops from 60.73% of total end use in 2016 to 40.66% in 2040 in CREO SPS, whereas in WEO NPS, it only declines from 56.61% to 53.05%, representing an absolute increase in the amount of consumption until it flattens from 2035 to 2040. This is because CREO assumes, for both scenarios, that the energy intensity of Class I industry (such as steel, cement, and nonferrous and ferrous metal) will be reduced to the same intensity level as the Class I industries in OECD and European Union (EU) countries in 2015, which is more than a 50% reduction from China's own 2015 levels. CREO also assumes that the energy intensity of Class II industry (such as food, textile, electronic equipment, and machinery manufacturing) will be reduced to EU levels. Between the two scenarios of the same study, the industry sector tends to represent a slightly higher percentage of total consumption in the low-carbon scenario than in the reference scenario. The industry sector as a portion of total consumption is 1.22% higher in CREO B2S in 2040 than in CREO SPS. Similarly, the industry sector as a portion of total consumption is 1.48% higher in WEO SDS in 2040 than in WEO NPS.

The biggest difference between CREO and WEO in terms of end use by sector is the size of the transport sector.[307] In CREO SPS, the transport sector grows from 20.74% in 2016 to 33.59% in 2040; in WEO NPS, the transport sector starts at 15.52% in 2016 and grows to 20.05% in 2040. CREO assumes a vehicle stock of 500 million by 2050, with the majority being passenger vehicles. WEO assumes 374 cars per 1,000 people in 2040 in NPS, which translates to around 522.85 million vehicles. This suggests that CREO assumes a much more energy usage per vehicle than WEO.

The buildings sector demand remains relatively stable as a percentage of total consumption in both WEO scenarios, whereas it rises significantly in both CREO scenarios.

In fact, as a percentage of total energy consumption, the buildings sector slightly declines from 22.77% in 2016 to 22.72% in 2040 in WEO NPS and decreases to 21.82% in 2040 in WEO SDS, reflecting WEO's relatively more aggressive building efficiency assumption than CREO's.

Figure 18-5. Energy use comparison (CREO 2017 SPS and WEO 2017 NPS)

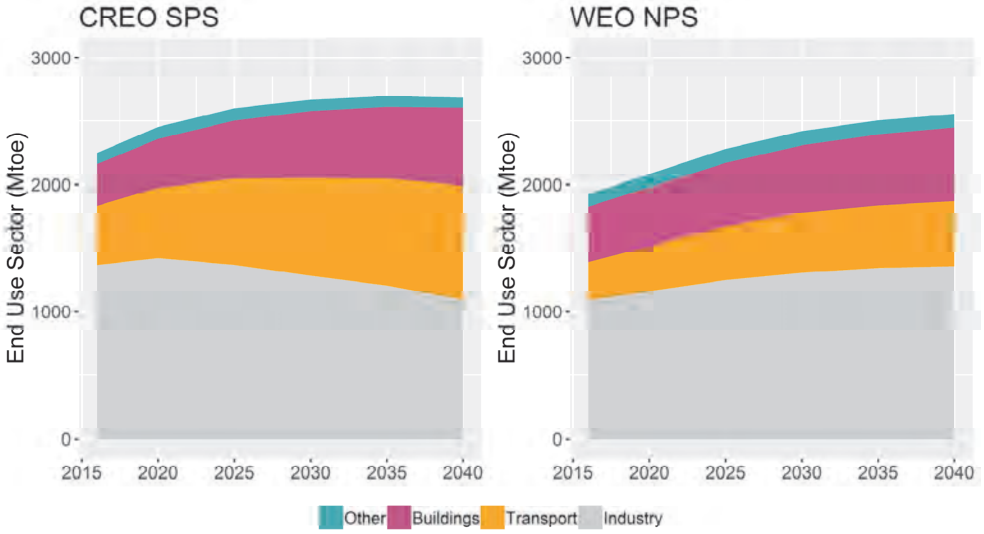
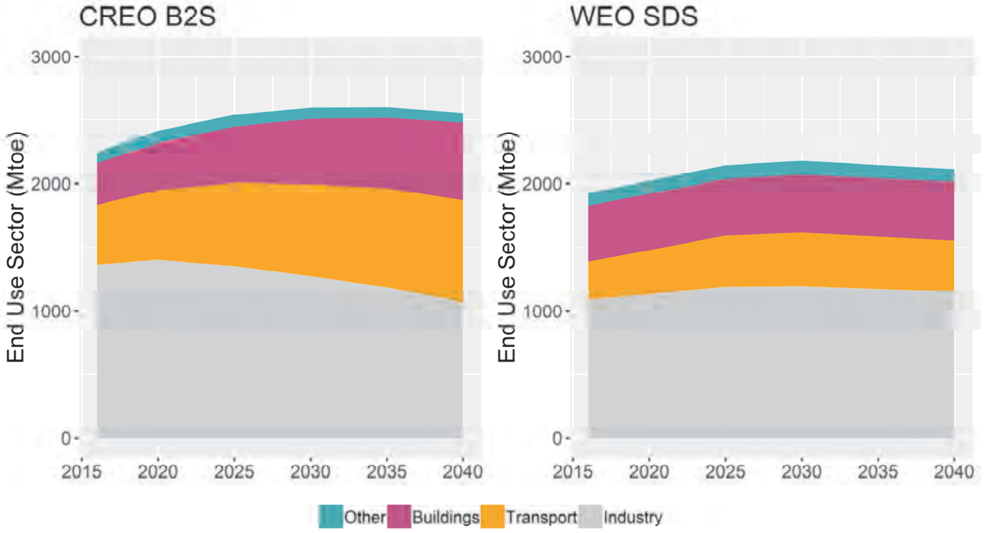


Figure 18-6. Energy use comparison (CREO 2017 B2S and WEO 2017 SDS)



Power Sector Capacity and Generation

CREO SPS takes a more aggressive position than WEO NPS for changes in the power sector, both in terms of total load growth and renewable development. The total generation in CREO SPS in 2040 is 1,005 TWh (9.83%) more than the total generation in WEO NPS. The total installed capacity in CREO SPS in 2040 is 216 GW (6.45%) higher than that in WEO NPS.

The coal capacity reaches peak at 2025 in CREO SPS and steadily declines from 2025 to 2040. By 2040, coal only accounts for 17.93% of the total installed capacity in CREO SPS, compared with 59.77% in 2016. WEO NPS reflects a business-as-usual outlook, with a continuous, slow increase in the amount of coal capacity, from 945 GW in 2016 to 1,096 GW in 2035, and a slight decline thereafter. As a percentage of total generation capacity, coal capacity decreases from 58.14% in 2016 to 32.47% in 2040 in WEO NPS.

Another notable difference is the amount of natural gas generation in CREO and WEO. In WEO NPS, more than 200 GW of natural gas is deployed by 2040, generating 832 TWh of electricity in that year, whereas the natural gas deployment in CREO SPS continuously drops from 70 GW in 2016 to only 12 GW in 2040, generating only 2 TWh in 2040. This is because the assumption for the cost of natural gas is relatively high in CREO compared with WEO.

As for renewable energy development, CREO SPS has greater wind deployment than WEO NPS. CREO SPS has 1,403 GW of wind and 821 GW of solar PV in 2040. In contrast, WEO NPS has 593 GW of wind and 738 GW of solar PV. An examination of the CREO constraint shadow prices shows that the deployment of wind is mainly driven by the minimum capacity requirement placed on the technology, rather than by an economic choice of the model itself or by the carbon emissions constraint. CREO's solar PV and onshore wind capital costs are similar to those of WEO. If the model is allowed to freely optimize based on costs, more coal builds would be expected in CREO. As mentioned before, the CREO SPS results are a demonstration of CNREC's expectation of continuous government support for stated policies and implementation success of these policies.

As mentioned before, both nuclear and hydro development are impacted by policy and environmental issues. Therefore, both CNREC and IEA have relied on a consultative process in developing the assumptions for these technologies. In comparison, WEO NPS deploys more nuclear and hydro technologies than CREO SPS.

Oil technology use in the power sector remains minimal in both CREO SPS and WEO NPS.

As for emerging renewable technologies, CREO SPS deploys 25 GW of ocean wave technology and 35 GW of concentrating solar power (CSP) technology based on experts' input; whereas WEO NPS only has 1 GW of ocean wave technology and 16 GW of CSP in 2040. Another emerging renewable technology, geothermal, plays a minimal role in both CREO SPS and WEO NPS.

Figure 18-7. Power sector installed capacity comparison (CREO 2017 SPS and WEO 2017 NPS)

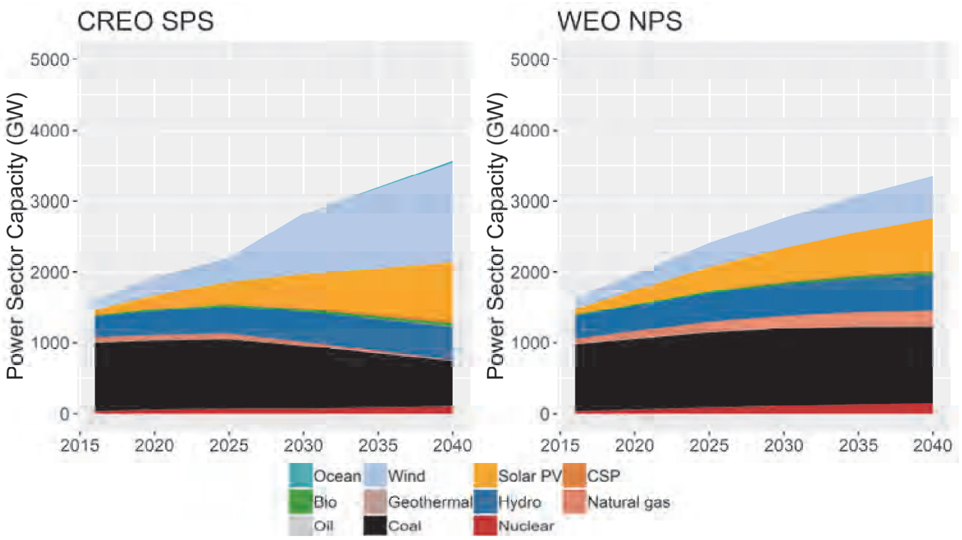


Figure 18-8. Power sector installed capacity comparison (CREO 2017 SPS and WEO 2017 NPS)

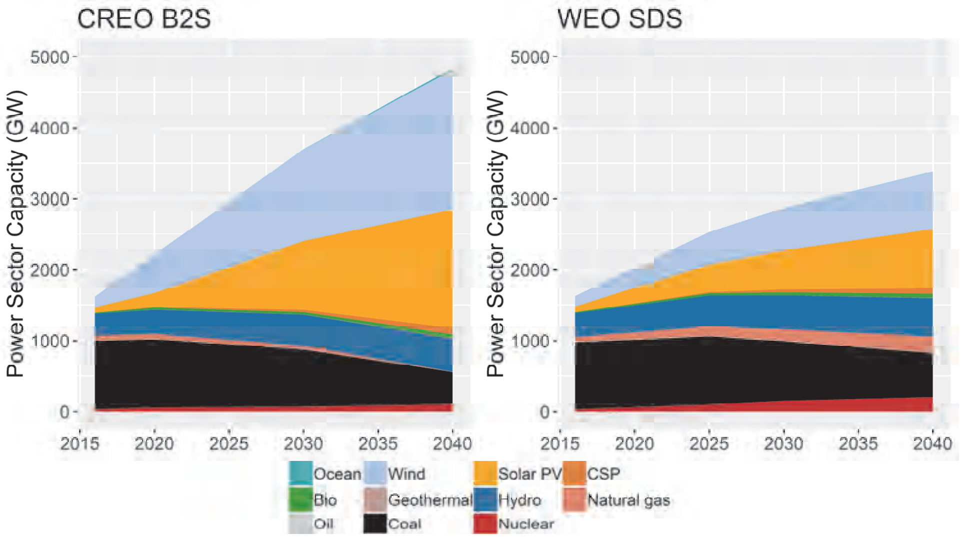


Figure 18-9. Power generation comparison (CREO 2017 B2S and WEO 2017 SDS)

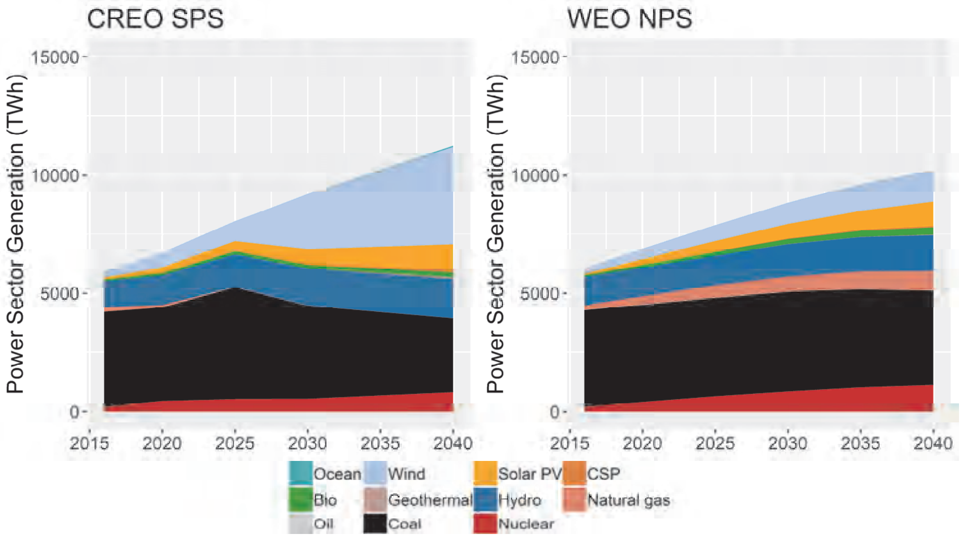
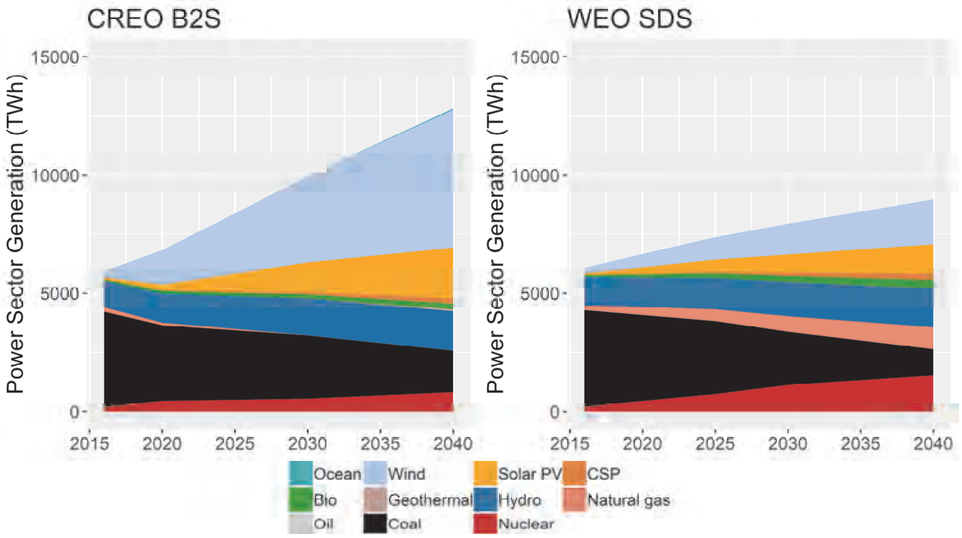


Figure 18-10. Power generation comparison (CREO 2017 B2S and WEO 2017 SDS)



The most significant difference between the CREO B2S and WEO SDS is the load. CREO B2S assumes very high levels of electrification with the new load met by renewable generation. In contrast, WEO NPS reduces total load in 2040 by 1,258 TWh (14.02%) relative to CREO SPS, representing improvements in energy efficiency outweighing load increase through electrification. As a result, the CREO B2S total generation is 12,822 TWh in 2040, which is 1.43 times the total generation in WEO SDS. The total installed capacity in CREO B2S is also 1.43 times the total capacity in WEO SDS.

The increased load in CREO B2S is largely met by the additional wind and solar (PV and CSP) capacity. By 2040, wind and solar account for 81.44% of the total installed capacity and 69.38% of the power generation in CREO B2S. In comparison, wind and solar account for 50.97% of installed capacity and 48.73% of the generation in WEO SDS.

The other technologies do not see a significant change between the reference scenario and the low-carbon scenario. Nuclear technology and ocean technology stay the same in CREO SPS and CREO B2S. Ocean technology stays the same in WEO NPS and SDS, but nuclear increases by 415 TWh in WEO SDS compared with WEO NPS.

Storage

CREO 2017 assumes significantly greater storage and electric vehicle (EV) smart charging deployment than WEO 2017. WEO assumes 35 GW of grid-scale storage application in 2030 and 70 GW in 2040 for both scenarios. In comparison, CREO SPS has 218 GW of storage by 2030 and 391 GW by 2040; CREO B2S has 418 GW of storage by 2030 and 585 GW by 2040.

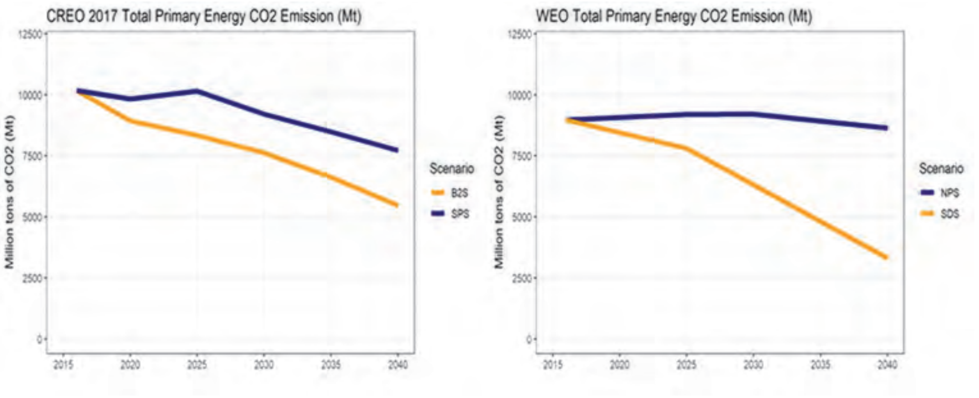
The EV adoption assumption and the availability of repurposed batteries are the main drivers behind this difference. In CREO SPS, 133 GW of the storage capacity is from repurposed EV batteries in 2030, and 259 GW in 2040. In CREO B2S, 333 GW of the storage capacity is from repurposed EV batteries, and 489 GW in 2040. Note that China is in an early stage of EV deployment and currently there is no commercial application of repurposed EV batteries yet, but the Ministry of Industry and Information Technology and six other departments joined established a guideline to encourage the research of EV battery recycling in February 2018. In addition, CREO assumes a 100 million EV stock in 2030 and 400 million by 2050, which averages to roughly 15 million annual EV sales between 2030-2050.[308] In contrast, WEO's assumes 1.8 million annual EV sales in 2030 and 9.5 million in 2040.

The Medium- to Long-Term Auto Industry Development Plan establishes a target for new energy vehicle sales to reach more than 2 million per year by 2020 and account for more than 20% of total vehicle sales in 2025.[309] Longer-term official plans are not available at the time of this writing.

Carbon Emissions

Total carbon emissions in CREO 2017 and WEO 2017 are different for both sets of scenarios. In short, CREO SPS is more aggressive in carbon reduction than WEO NPS; CREO B2S is less aggressive in carbon reduction than WEO SDS.

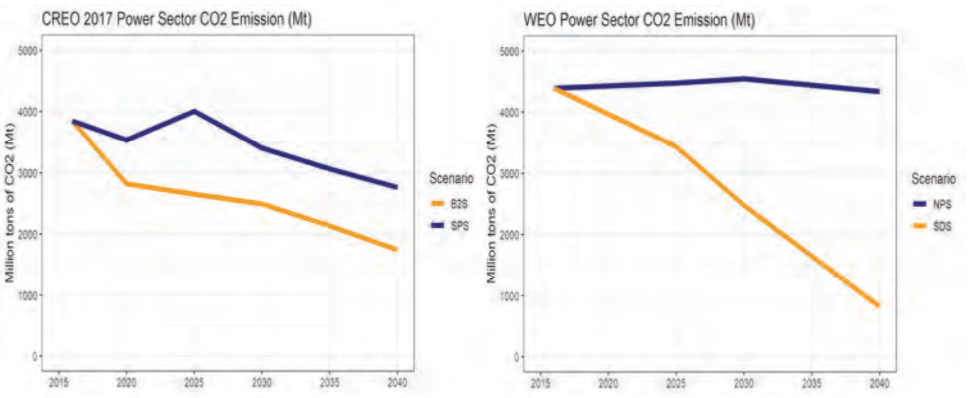
Figure 18-11. Primary Energy CO_2 emissions comparison (CREO 2017 and WEO 2017)



For primary energy CO_2 emissions, CREO 2017 and WEO 2017 start at different CO_2 emission levels for 2016. 2016 CO_2 emissions in CREO 2017 is 10,167 Mt, 13.32% higher than the 2016 CO_2 emissions in WEO 2017, which is 8,973 Mt. This is partly because the 2016 primary energy demand is 4.12% higher in CREO 2017 than in WEO 2017. In addition, CREO SPS shows gradual reduction in the near term (now to 2020) and then an upward emissions trajectory from 2020 through 2025 before the final decline after 2025. WEO NPS has gradual CO_2 emission increases from now to 2030, followed by gradual decline after 2030. By 2040, CREO SPS sees a 24.03% reduction from its 2016 emissions level and WEO NPS sees a 3.79% reduction from its 2016 emissions level.

CREO B2S shows steeper CO_2 emissions reduction from now to 2020 (reaching 8,933 Mt), followed by much more gradual reduction to 5,470 Mt by 2040. In contrast, WEO SDS shows gradual decline in CO_2 emissions from now to 2025 (reaching 7,802 Mt), followed by very steep reduction to 3,309 Mt in 2040. By 2040, CREO B2S shows a 46.20% emissions reduction from its 2016 level, and WEO SDS shows a 63.12% emissions reduction from its 2016 level. As a result, CREO SPS has a total delta of 29,805 Mt more aggregated CO_2 emissions from 2016 to 2040 than WEO SDS. Other studies have also shown a wide range of future carbon emissions under low-carbon or similar scenarios. [310] For example, the Energy Modeling Forum 27 study shows that around 4,870 Mt of CO_2 emissions must be reached by 2040 to meet the 450 ppm CO_2 emissions target. [311] In the SWITCH-China model, the scenario that meets the Intergovernmental Panel on Climate Change (IPCC) target would result in 2,957 Mt of CO_2 emissions by 2040. [312]

Figure 18-12. Power sector CO_2 emissions comparison (CREO 2017 and WEO 2017)



CO_2 emissions from the power sector follow similar trends as above, but with more pronounced differences. In other words, the trends and patterns observed in the primary energy CO_2 emissions are mainly driven by those of power sector CO_2 emissions. Here the power sector CO_2 emissions in 2016 is 14.16% higher in WEO 2017 than in CREO 2017.

Power sector CO_2 emissions show a clear downward-upward-downward pattern in CREO SPS, indicating the model's tight carbon constraint for 2020. In general, CREO SPS shows greater carbon reduction than WEO NPS.

Similar to primary energy CO_2 emissions, WEO SDS shows much more drastic reduction after 2025 than CREO B2S. By 2040, total CO_2 emissions from the power sector is 1,745 Mt in CREO B2S, which is 2.12 times the power sector CO_2 emissions (820 Mt) in WEO SDS. [313]

Key Observations from the Comparison

The comparison between CREO 2017 and WEO 2017 raises a few key issues, including input data alignment, CO_2 emissions constraints, and demand-side and natural gas assumptions.

First, better input data alignment could help anchor both studies to the same baseline and help readers more easily compare and understand the results from the CREO and WEO scenarios. This may require closer coordination between CNREC and IEA, improved data transparency, and standardization of data sources. These practices support data development, as feedback and critique can take place before finalizing datasets. Input data alignment could resolve current discrepancies between the two studies regarding 2016 end- use sector energy demand, CO_2 emissions, and, to a lesser extent, total primary energy demand.

Second, while both CREO B2S and WEO SDS are set to achieve the two-degree target for China, the total aggregated CO_2 emissions in CREO B2S from 2016 to 2040 is significantly higher than in WEO SDS. This represents a discrepancy regarding the total overall carbon budget for China consistent with the Paris Agreement. While this disagreement is likely to persist in future studies, it highlights the importance of detailing the data and methodology behind the carbon budget calculation for both studies. In addition, CREO 2017 has a tight carbon constraint for the year 2020, resulting in a V-shaped CO_2 emissions growth pattern before reduction starts in 2025. This constraint has been relaxed in CREO 2018 to result in a smoother trajectory of carbon emissions development in the two CREO scenarios.

Third, the demand side is very different between CREO 2017 and WEO 2017. CREO B2S assumes a large amount of electrification, whereas WEO SDS assumes significant energy efficiency in the final energy consumption. As China goes through rapid urbanization, there are huge uncertainties regarding its future economic and energy growth. Therefore, sensitivity analysis may be needed to fully explore the impact of different future load growth patterns: high electrification/high economic growth, or high energy efficiency/low economic growth. Similarly, there is a wide gap in EV and storage deployment between CREO and WEO, so a sensitivity analysis may be needed to provide insights into the amount of storage (including EV smart charging) needed in the system and the value it provides.

Fourth, natural gas deployment is a major difference between CREO 2017 and WEO 2017 in the power sector. Such difference represents CNREC's and IEA's best estimation of the natural gas resource available and the capital cost and fuel cost trajectory relative to other technologies. CREO 2018 increases the natural gas assumption in the power sector, reflecting the policy direction behind China's target of 8.3–10% natural gas in primary energy consumption by 2020, established in the Natural Gas Development 13th Five Year Plan.[314]

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chapter.

[250] See also chapter 2.2 on the status of the energy transition in Germany.

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