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

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China Renewable Energy Outlook

2017

Energy Research Institute of Academy of Macroeconomic Research/NDRC

China National Renewable Energy Centre

China Renewable Energy Outlook 2017

Implementing Unit

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能源研究所
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10 November, 2017

“It is important to protect the environment while pursuing economic and social progress so as to achieve harmony between man and nature and between man and society”

President Xi Jinping

Keynote speech at the opening of

The World Economic Forum in Davos, January 2017

Foreword

China Renewable Energy Outlook 2017 (CREO 2017) is the second Outlook produced by the "Boosting Renewable Energy in China" program within China National Renewable Energy Centre (CNREC). Against the backdrop of overarching Chinese development strategies and the international experiences from front-runner countries, this year's Outlook focuses on China's possibilities for low-carbon energy transition towards 2050, and the short-term actions needed to remove obstacles for renewable energy development and quickly move in the right direction.

Our research is based on CNREC's scenario development and modelling of for the Chinese energy system. We examine the impact of the current and planned policy strategies for the energy transition in a scenario called "Stated Policies Scenario" , and in a "Below 2 °C Scenario" we examine the additional steps needed if China follows the direction set out in the Paris Agreement in a "Below 2 °C Scenario". In addition, we look deeper into key enabling policy conditions for the energy transition, focusing on renewable energy subsidy reform, power market reforms, carbon pricing, grid development and the development of distributed energy systems.

The Outlook has been prepared by the CNREC team in close collaboration with national and international partners, and the research has been made possible by funding from the Children's Investment Fund Foundation and from the Danish and German governments. I would like to express my sincere gratitude to the donors and our partners for their support and hard work.

Wang Zhongying

Deputy 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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Executive Summary

Summary

Policy Strategies in Place But Stronger Action Needed

China has started the transformation from a coal-based energy system with high environmental costs to a low-carbon and environmentally friendly energy system. Our analyses show that the right strategies for policy measures are on the table, but the success of the energy transition depends on strong implementation of the supporting policies - the power market must be enforced in a way that stimulates flexibility and integration of renewable energy (RE), the carbon pricing mechanisms must ensure sufficiently high carbon prices to make an impact on CO_2 emissions and the support schemes for RE must stimulate cost-efficient deployment of RE projects. Also, more ambitious targets for RE and for coal reduction are needed in the near term for China to be able to comply with the Paris Agreement requirements for a "well below 2 °C" future.

The Overall Policy Strategies are in Place

The Chinese government already today has a basket of policy strategies and policy measures, which leads in the direction of sustainability and a low-carbon energy system. Green development, together with 'innovation, coordination, greenness, openness and inclusiveness', profiles China's 'five key development concepts'; ecological civilisation is not a buzz-word, but was listed along with economic, political, cultural and social progress as one of the five goals in the country's overall development plan and deeply anchored in the government's four-pronged comprehensive strategy; the Chinese commitment to the Paris agreement and the adhering to environmental friendly cooperation to respond to climate change demonstrates readiness to take action against one of the main threats to mankind's future living conditions; and the ongoing implementation of the national environmental action plan, the power sector reforms and the national emission trading system shows that the journey to a deep energy transition has started.

Coal Reduction and a High RE Share in 2050at Reasonable Costs

Our analyses show that a strong implementation of these policy measures, as in the Stated Policies Scenario, will reduce the use of coal to one third of today's level by 2050, ensure a peak in CO_2 emissions well before 2030, and thereafter significantly reduce emissions to a level of around 5,000 million tons in 2050 – half of today's emissions. Non-fossil fuels will contribute 60% of the energy supply in 2050, significantly higher than the official target of reducing coal dependency to half of the supply. In 2050, after investments in the energy system transformation, the electricity cost (in fixed prices) will be at the same level as today's but the system will be much more sustainable and robust than the current system, with less dependence on fossil fuels and reduced pollution at local, regional, and global levels.

Massive Investments Give Massive Benefits

The energy transition itself requires massive investments in grid infrastructure and in RE technologies. In the short term this will lead to higher power costs, but with many benefits:

- Significantly improved air quality and lower pollution
- Lower fossil fuel prices for economic sectors not able to rapidly shift to electricity or non-fossil fuels
- Promotion of job creation in future-oriented technologies, compensating for jobs lost in the coal mines and in manufacturing of old technologies – in line with the Chinese strategy for aggressive innovation.

Figure 1 The two scenarios in CREO 2017

Stated Policies Scenario	Below 2° C Scenario
•Implementation of the Stated Policies and extrapolation of the current policy trends toward 2050 including the official target to reach "the carbon emission peak by 2030 and to strive to achieve it earlier"	•Implementation of the Paris agreement target to reduce the impact of the GHG emission to a Below 2° C temperature increase

Cost Reduction, Carbon Pricing and Power Markets are Main Drivers

The energy transition and coal power reduction are driven by three key enabling conditions. In our analyses, we assume that technology development for renewable energy—driven by China's innovation strategy and international trends—will result in a continuation of recent years' reduction of costs and increases in efficiency, leading to a lower cost of energy from these technologies.

Second, we assume a strong implementation of power markets as a non-reversible direction and as a main tool to ensure integration of variable renewable energy generation.

Third, we assume that carbon pricing will be efficiently implemented, resulting in a price of carbon emissions which significantly influences investment decisions in the energy sector. In our analyses we assume a long-term carbon price of 100 RMB per ton of CO_2 in the Stated Policies Scenario, which is sufficient to quickly make renewable energy competitive with coal.

Strong Policy Implementation Guarantees the Energy Transition

A rapid and successful implementation of these policy measures and innovation strategies will ensure that the energy transition can be realised without major obstacles. Should these policy measures lag in their implementation or if implementation is carried out ineffectively, it could lead to a lock-in of fossil-fuel technologies and severe barriers for deployment and integration of renewable energy technologies.

Hence, policy enforcement, especially for the short-term implementation is key to the success of the long-term deep energy transition.

Stated Policies are Too Weak for a "Well Below 2 °C" Future

Our analyses show, that even a successful implementation of the Stated Policies Scenario is not sufficient to comply with the Paris Agreement requirements for a "Well Below 2 °C" future. It will fulfill China's current Nationally Determined Contribution (NDC), but as most countries participating in the Agreement already realise, it will not lead to a sufficient reduction of CO_2. We find that the Stated Policies Scenario leads to a CO_2 emissions reduction pathway which is too slow and too weak.

We have analysed which further steps are necessary for China to ensure a CO_2 reduction in compliance with the Paris Agreement, based on what we consider to be a CO_2 budget scheme for China to achieve a "below 2 °C" future. The budget is prepared based on a combination of Chinese and international studies and provides a rapid energy sector CO_2 emissions reduction from today's level of 10,000 Mton to 9,000 Mton in 2020, 8,000 Mton in 2030 and 3,000 Mton in 2050.

Emissions Reduction Requires Accelerated Action

To comply with this emissions budget, China must accelerate the reduction of coal and rapidly introduce more renewable energy into the energy system. Compared to the Stated Policies Scenario, our analyses show that the Below 2 °C Scenario provides for 305 GW additional renewable power capacity in 2020, growing to 1,518 GW additional capacity in 2050. The additional capacity is mainly wind in the beginning and mainly solar toward the end of the period. The coal fleet is also phased out more quickly in the Below 2 °C Scenario, with 16 GW less coal capacity in 2020 and 220 GW less coal capacity by 2050. To stimulate the emissions reduction in the end-use sectors we assumed a higher electrification rate in the Below 2 °C Scenario for the transport and industrial sectors.

More Ambitious RE and Non-fossil Energy Targets

The targets in the 13th Five-Year Plan (FYP) regarding power generation capacity development toward 2020, defined in 2015, have already proven conservative in light of recent developments. We estimate that the power generation capacity for wind, solar and bioenergy will all significantly exceed the plan's target by 2020. This also implies that the non-fossil fuel share of total energy consumption will exceed the target of 15% by 2020. This allows for rapid electrification of the end-use sectors without increasing CO_2 emission from the whole energy system.

Both scenarios deploy more RE capacity than the targets in the 13th FYP. The non-fossil fuel share is higher and the coal reduction is greater than the official targets in both scenarios

Table1: 2020TargetsAndScenarioAchievements

	13th FYP	Stated Policies Scenario	Below 2 °C Scenario
Total Capacity	676 GW	814 GW	1,119 GW
Hydropower	340 GW	341 GW	341 GW
Wind	210 GW	259 GW	549 GW
Solar	110 GW	188 GW	200 GW
Biomass	15 GW	26 GW	29 GW
Other RE	0.55 GW	0.58 GW	0.58 GW
Share of Total Energy consumption			
Non-fossil Fuel	15%	19%	26%
Coal	58%	55%	51%

Requirements for Flexible Dispatch of Coal Power Plants and Interconnectors

To ensure the integration of a larger amount of new variable renewable energy capacity, operational requirements for thermal power generators and dispatch centres must be established to ensure more flexible use of transmission lines and interconnectors between provinces. Local governments must be urged to cooperate on joint dispatch and joint utilisation of renewable energy resources.

Coal Power Plants Must Adapt to a New Role as Flexibility Providers in the Medium Term

The Below 2 °C Scenario clearly demonstrates that there will be no need for new coal power capacity in the future power system. The current permitting practice for new coal power plants should be strengthened even further and a temporary ban on new coal power plants should be implemented as soon as possible to avoid significant stranded assets. As the electric market reform develops, planned full-load hours will be gradually phased out and the existing annual power generation plans discontinued. Hence power producers need to consider the market demand and carefully plan their own power generation accordingly. Already today coal power producers are becoming aware of such market risks. New power plants are facing increasing risks, i.e. no guaranteed feed-in tariff, rising production costs, falling prices of renewable competitors and no long-term power agreements with fixed prices.

Recommendations For Actions 2017-2020

Based on extensive analysis and considering the industry, technology, and policy developments of the past few years and their outlook for the near and medium-term future, CNREC offers the following recommendations:

RE and Non-fossil Fuel Targets

- The 13th five-year plans RE capacity targets for 2020 are minimum targets. We recommend that the RE development should go beyond these targets: Solar from 110 GW to 200 GW, wind from 210 GW to 350 GW, bioenergy from 15 GW to 30 GW – a total of 580 GW.
- The non-fossil energy share could go beyond 13th five-year plan targets: From 15% to 19% in 2020. Considering the Below 2 °C temperature control target, the development targets need to be further enhanced.

Increase Efforts to Reduce Coal Consumption

- Stop approval of new coal power plants.
- Reduce the coal share of the primary energy consumption from 64% to 33% in 2030.
- Establish requirements for coal power plant flexibility and gradually remove planned full-load hours.
- Provinces with economies heavily dependent on coal should immediately develop a plan to transition away from coal.

Power Sector Reform

- Expand and accelerate the whole-sale market pilots and regional coordination of market pilots
- Include dispatch of interconnectors in the market pilots by removal of interprovincial trade barriers
- Prevent lock-in of coal power production caused by bilateral trading contracts
- Clear the way for the next step of power market development in China

ETS System

- Strongly focus on the viability of the national emissions market – avoid pitfalls from grandfathering and new policy impediments.
- Set a floor price for CO_2 that will impact investment decisions

RE Subsidy Reform and RE Incentive

- Increase the RE surcharge to ensure sufficient funding in the transition period
- Implement a RE quota system, which supports the implementation of mandatory and voluntary combination of green certificate trading system
- Increase the use of competitive auctions to lower the subsidy price for large-scale wind and solar projects

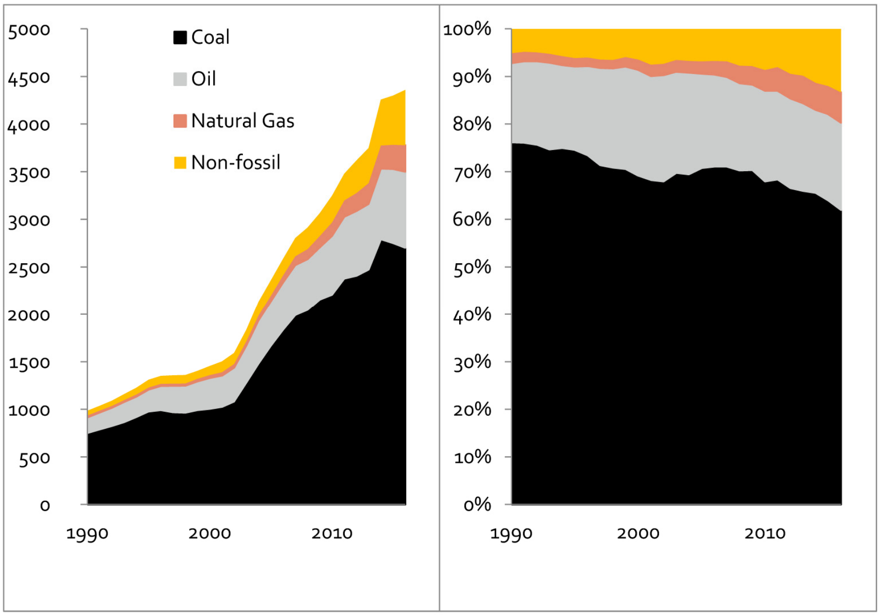
Introduction

Economic Growth – With a Price

China has undergone tremendous development since the implementation of economic reform and opening. Nearly three quarters of a billion people have over the past 20 years been lifted from extreme poverty into more decent living standards, and the Chinese society is closer than ever to become a "moderately prosperous society" – the goal for 2020.

This development comes with a price. Economic growth has been enabled through enormous growth in energy consumption. From 1978 to 2016, China's total energy consumption soared from 570 Mtce to 4,360 Mtce; the share of fossil fuel in the energy mix has been more than 85%, and coal's share higher than 60-70%. The largely coal-dependent energy consumption has resulted in severe environmental damages. Most visible is the health damaging air pollution affecting most cities in China, but severe water pollution and land degradation have also been the price paid for the growth in energy consumption.

Figure 2 Development of primary energy demand in China from 1990 to 2016 by fuel type, in absolute value (Mtce) and in percent of the total consumption each year



New Pathways for Sustainable Growth

China's economy has entered the "new normal" – with lower growth rates and profound structural changes in the Chinese economic sectors, with the service sector gradually substituting for the industry sector as the main driver for the Chinese economy. The country's GDP per capita is low compared with other countries, and the long-term goal for the development of China is stated in its the second centenary dream proposed by the Chinese government: to "uplift the per capita GDP to the level of moderately developed countries" to fulfil the vision of China becoming a modern socialist country that is "prosperous, strong, democratic, culturally advanced and harmonious" by 2049. Therefore, stable economic growth is still central to the process of modernising China, and the primary task under the economic "new normal".

It is clear that future economic development cannot follow the same pattern as over the past 20 years. Although energy services are still needed to sustain the momentum of growth, the energy consumption and supply must adhere to the ecological boundaries for sustainable development. The concept of an "ecological civilisation" has been designated as a leading development strategy by the Chinese government, and the concept of ecological civilisation has been consolidated into the integrating development of the "five-in-one" approach and the coordinated promotion of the "Four-Pronged Comprehensive Strategy". Meanwhile, green development joins innovation, coordination, openness and inclusiveness as China's five new major development concepts.

China is gradually shouldering an increased active role in promoting multilateral international responsibility for coping with climate change. As a country in the early stage of its energy transition, China used to have a highly coal dependent economy. But as of today, China is already able to display some world-class achievements, including the highest capacity of installations of wind, solar and hydro power of any country, and a strong foundation in the renewable energy industrial base with the potential to enable decarbonisation both at home and abroad.

Energy Transition for a Low Carbon Future

Hence, the question here is not whether to have an energy transition, the question is how to facilitate the transformation of the current energy system into a sustainable system, and how to utilise the energy transition as a strong driver for the economic development of China in the future even through 2050.

This is the overall theme for the 2017 China Renewable Energy Outlook. Together with NDRC's Energy Research Institute and with the support of international experts, CNREC has analysed two roadmaps or scenarios for the development of Chinese energy system. The first, the Stated Policies Scenario, illustrates implications of a continuation of current

Chinese energy and environmental policies. The second, the Below 2 °C Scenario, analyses an energy development path that is influenced by the Chinese commitment to the Paris Climate Agreement, focused on "holding the increase in the global average temperature to well below 2 °C above pre-industrial levels".

Both scenarios are ambitious in the sense that drastic changes in the energy system are necessary to fulfil the current Chinese policy strategy and fulfil the intentions of the Paris Agreement.

The Paris Agreement – A Challenging Goal to Fulfil

The Paris Agreement sets the goal of "holding the increase in the global average temperature to well below 2 °C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 °C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change". The objectives are clear, and imply drastic reductions in the global emission of CO_2. The challenge is huge – global emissions should peak as soon as possible and reach net-zero emissions in the second half of the century. The parties behind the agreement have committed themselves to National Determined Contributions (NDCs), measures for the individual countries to reduce greenhouse gas emissions. The International Energy Agency (IEA) has clearly demonstrated in its World Energy Outlook 2016 that the current NDCs are not nearly enough to reach a peak in global energy-related emissions and to limit the temperature rise to less than 2 °C.

Climate change and related commitments to the Paris Agreement have become a main driver of the energy transition in most regions and countries. The European Union's energy transition is driven by the goal of reducing GHG emissions by 80-95% by 2050 compared to 1990 levels, with an intermediate goal of 40% reduction in 2030 and with targets for energy efficiency and renewable energy deployment. Countries including Germany and Denmark have long-term goals of a low-carbon energy system or even one fully independent of fossil fuels. In the USA, several states, cities, private companies and universities are committed to low-carbon development, which to a large extent mitigates the current uncertainty about the Trump administration's approach to greenhouse gas reduction.

The many activities to move towards an implementation of the Paris Agreement clearly demonstrate that a broad range of measures with strong policy commitments and leadership are necessary to ensure the future sustainability of the global energy system.

Today's Energy Systemand Challenges

Fossil Fuels Still Dominate the Energy System

Energy consumption in China is dominated by industry, although other sectors have increased their share in recent years. The total final energy consumption amounted to around 3,230 Mtce in 2016, with 61% of the energy consumption related to industry, 21% related to transport, and 14% related to buildings.

Coal is the dominant fuel in the end-use sectors. In 2016, 39% of the final energy consumption was coal, 27% was oil, 19% electricity, natural gas 7%, district heating 5%, and bioenergy 2%.

In the power sector, renewable energy had a share of 26% of electricity production in 2016, and non-fossil fuels accounted for 29.5%. Coal was used for 67% of the power generation with natural gas covering the remaining 3% of the generation.

The total primary energy supply in China was about 4,360 Mtce in 2016. Coal covered 65% of the supply, oil 21% and natural gas 6%. The share of non-fossil fuels was 8% calculated on energy basis (13% calculated by the coal substitution method). The share of renewables was 11% calculated by the coal substitution method.

Despite a tremendous growth in renewable energy in China over the past 10 years, the current Chinese energy system is far from the development targets of being clean, efficient, safe, and sustainable.

Air Pollution Remains Severe

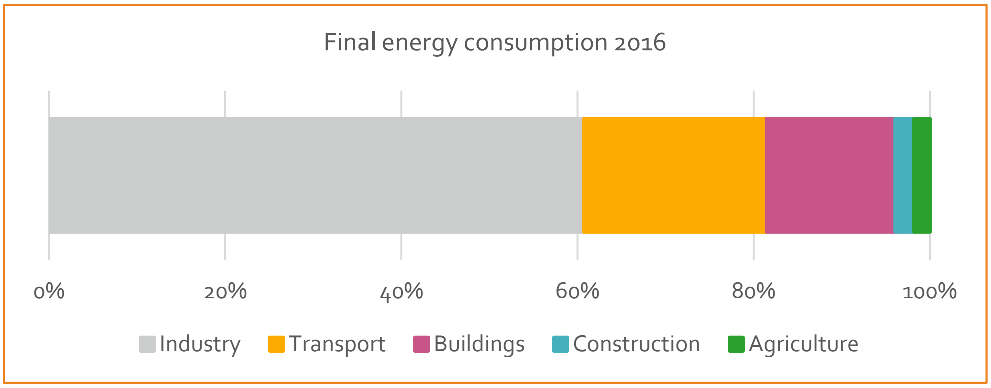
Air pollution from coal power plants, industrial coal use and from fossil fuelled cars has created serious problems in most Chinese cities. The Chinese government has air pollution reduction as one of its highest priorities, but the progress towards clean air is slow. Also, water pollution and soil degradation are environmental problems with the potential risk to jeopardize future Chinese sustainable development.

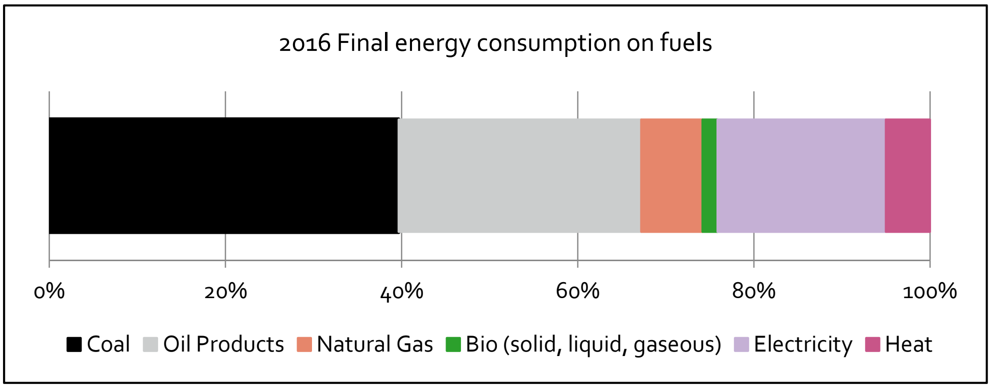
Concerning Addiction to Fossil Fuels

Today's dependency of fossil fuels in China's energy consumption structure is also creating a dependency on import of energy. Most notable is oil, where China imported around two thirds of its oil consumption in 2016.

For coal, some provinces are so dependent on the coal-economy, from coal mining to coal power production, that this has created a "lock-in" to coal which constitutes a barrier for reducing the use of coal in China.

Figure 3 The final energy demand in 2016 by sector, and by primary and secondary fuels in percent of the total final energy demand



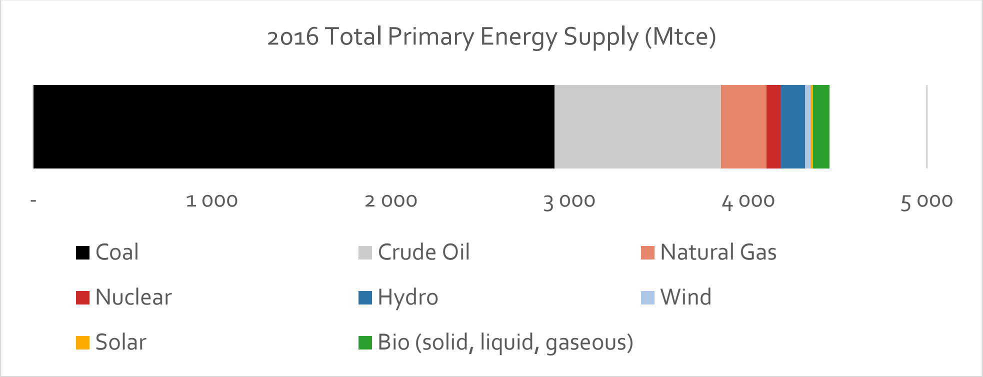


Renewable Power Resources are Wasted due to Lack of Integration

Forced reduction of power production from wind and solar power plants – also called "curtailment" – has been a problem in China for several years.

Curtailment is a clear sign that renewable energy is not yet well integrated into energy system. In 2016, more than 17% of the total power production from wind was rejected due to curtailment, resulting in the waste of renewable energy resources and increased wind power production costs. Increased coal power production associated with RE curtailment increases air pollution and greenhouse gas emissions. Also, power production from solar and to a lesser extent hydropower in key regions has also been curtailed in recent years.

Figure 4 Primary energy demand in 2016 by fuel type



Inflexible Power System with Institutional Challenges

The current power system is still influenced by the last 15 years' development strategies, which – successfully – aimed for security of electricity supply to power the rapidly expanding economy. With today's "new normal" growth rates this approach has led to significant overcapacity of coal power plants with the risk of stranded investments and "lock-in" to fossil fuels in the future power system. Furthermore, the dispatch of power plants and power interconnectors are influenced by a traditional approach to power transactions, which fails to account for the variable nature of large-scale power generation from wind and solar power plants.

The ongoing power sector reform should solve these issues and create a whole new framework for power system operation and development. However, the implementation of the power market reforms is currently proceeding slowly. Joint goals are lacking for the different provinces, which often have conflicting interests when it comes to cooperation on market set-up and trading arrangements.

Need for RE Subsidy Reform

Today the deployment of RE in China is mainly supported by a feed-in tariff for produced electricity. The current subsidy system has several problems and a reform is needed to ensure more efficient support. The surcharge on electricity is not sufficient to ensure funding of the increasing number of projects. Also, tariffs are variable, tending to create an uneven flow of new projects when the tariffs are lowered. Thirdly, the feed-in tariff system is not well suited for the future power market reform and integration of RE power into power markets.

The need for support to renewable energy technologies mainly reflects inadequate pricing of fossil fuels. Fossil fuel prices currently do not reflect the full costs that the use of the fuels imposes on Chinese society. Environmental costs are not properly addressed and other support mechanisms for fossil fuels distort competition between the different energy technologies

Outlook Methodology and Assumptions

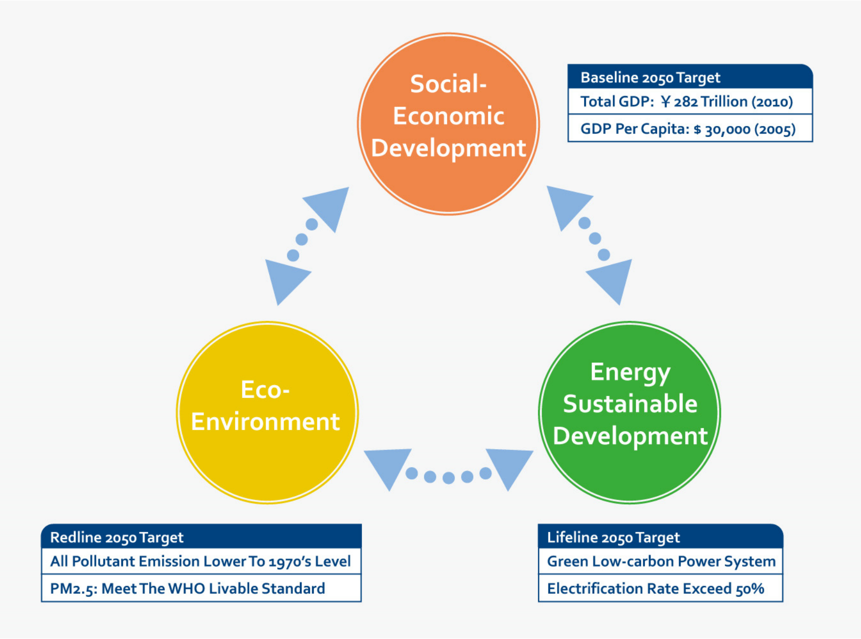
Forward-looking and Back-casting Scenario Approach

To obtain insight into future development trends for the Chinese energy system*, China Renewable Energy Outlook (CREO) uses a forward-looking approach starting from today's energy system and today's policy framework, and a back-casting approach that considers possible objectives for 2050 and identifies steps to get there. The combination of these methodologies keeps a focus on the long-term vision for the energy system while highlighting and planning to address near-term obstacles for the desired development.

This aligns with a Chinese research target that combines the vision of a "Beautiful China" with pragmatic short-term development strategies.

In the scenario settings, CREO uses the development strategy concepts of Four-pronged Comprehensive Strategy, the Five Development Concepts and the Five in One strategy to derive an innovative development scheme for the Chinese energy sector, called the Three-Line Development Concept. This is integrated into the scenarios and application of the results.

Figure 5 The "Three-line development" concept

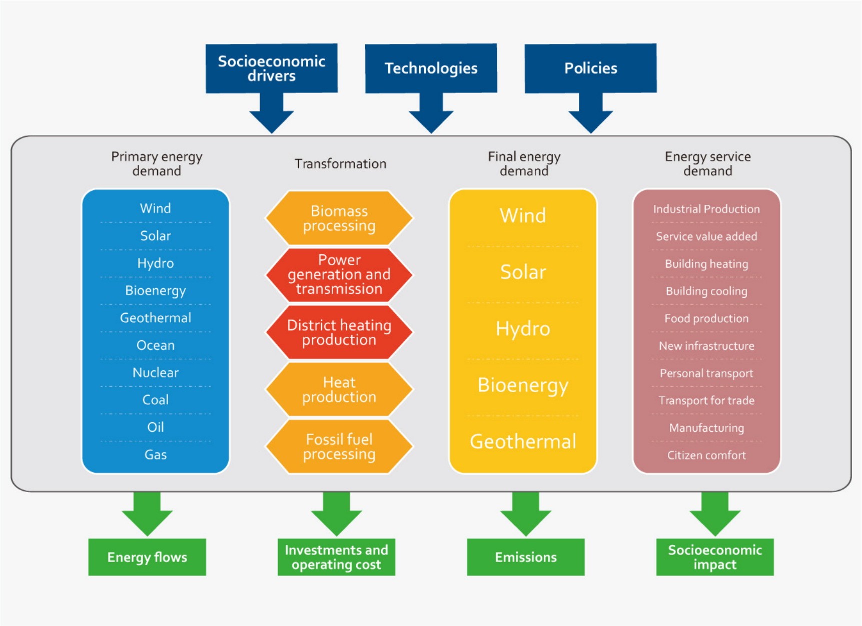


The scenarios are prepared using CNREC's scenario modelling tools, which cover the entire energy system and which can make least-cost optimisation of the dispatch of the power and district heating systems with given constraints. The models can also show the impact of policy measures (e.g., power and carbon markets).

Economic and Social Development Assumptions in Scenarios

In the scenarios, the assumptions of China's mid-century social and economic development scenarios are almost the same: it is assumed that in 2050 China's primary energy supply and end-use energy consumption structure will support a GDP at a level of 282 trillion RMB. The Chinese population is assumed to grow to 1.51 billion people in 2030 and then decrease to 1.38 billion people in 2050. The urbanisation rate (the share of people living in cities) is assumed to grow from 55% in 2015 to 68% in 2030.

Figure 6 The energy system modelled by CNREC modelling tools



* Note: Due to the scope of key data sources, our research does not include the Hong Kong Special Administrative Region, the Macao Special Administrative Region and Taiwan Province.

Carbon Constraints

The carbon emission constraints for the Stated Policy Scenario are based on the carbon emission intensity target declared by China, i.e., a reduction of 40%-45% and 60%-65% in carbon intensity by 2020 and 2030 respectively. In the scenario modelling the results show that these targets are not actual constraints on energy system development due to the other constraints and assumptions.

For the Below 2 °C Scenario we base the constraints on several different simulations from the IPCC AR5 database scenarios with >66% chance of staying Below 2 °C warming.

Table 2: Carbon constraints in the two scenarios

Scenario	Parameter	Year 2020	Year 2030	Year 2050
Stated Policies Scenario	Carbon Intensity compared to 2005 level	40-45%	60-65%	-
Below 2 °C Scenario	Carbon cap (Mt CO_2)	9,000	8,000	3,000

Carbon Market Development

In both scenarios, the CO_2-price projected to arise from the national emissions trading system (ETS), is implemented as a cost of CO_2 emissions.

In the Stated Policies Scenario, this implies that the Chinese national ETS creates a disincentive for CO_2 emissions in the power sector of 30 RMB/ton beginning 2017. This rises to 50 RMB/ton by 2020 and 100 RMB/ton in 2030. From here the price stagnates in the stated policies scenario, while in the Below 2 °C Scenario it increases further to 200 RMB/ton in 2040.

Table 3: Assumed price of emitting CO_2 in the two scenarios (RMB/ton)

	2017	2020	2030	2040	2050
Stated Policies	30	50	100	100	100
Below2°C	30	50	100	200	200

In the Below 2 °C Scenario, this CO_2 emissions price is a minimum level, which is increased as a modelling result to the level necessary to achieve the annual CO_2 emissions limit in the carbon budget.

Energy Targets

CREO assumes several energy targets and constraints should be fulfilled for the two scenarios (see the Main Assumptions summary at the right):

- The industrial structure adjustment and strong energy efficiency measures will efficiently control the too rapidly increasing final energy consumption in both scenarios
- Electrification, most extensively in the Below 2 °C Scenario, will be an important measure to reduce fossil fuel use in the end-use sectors; this is justified by the higher share of renewables in the power sector
- By 2050, China's electric vehicle stock is expected to be at least 400 million vehicles, equivalent to 80% of all vehicles, the cars will be used actively in the balancing of the power system
- The share of non-fossil fuels in final primary energy consumption should grow substantially towards 2050
- Construction of nuclear power plants in the inland is assumed not to happen, hence the nuclear power capacity is assumed not to exceed 120 GW through 2050

Table 4 Minimum RE capacity targets in the two scenarios for 2020

RE Capacity	809 GW
Hydropower	340 GW
Wind	259 GW
Solar	187 GW
Bio	24 GW
Other RE	0.55 GW

Table 4: Main Assumptions

Social and Economy

GDP 282,000 Billion RMB in 2050

Population 1.38 Billion people in 2050

Energy demand

Ambitious EE targets

2050 final energy consumption less than 3500 Mtce in both scenarios

Electrification (minimum)

2020: SP:20%, B2°C: 20%

2030: SP:25%, B2°C: 30%

2050: SP:40%, B2°C: 55 %

Electricvehicles

At least 400 million vehicles in 2050

Energy supply

Non-fossil fuel share (minimum)

2020: SP:15%, B2°C: 20%

2030: SP:20%, B2°C: 40%

2050: SP:60%, B2°C: 75%

Wind, Solar and Biomass Power Capacity

The deployment of wind and solar is limited by resource constraints. RE deployment to 2020 is guided by established targets for capacity deployment in the 13th FYP for Renewable Energy.

For each of the two scenarios there is an overall RE share as well as resource specific energy shares. Adding to this there are a few capacity targets to push development for offshore wind, solar photovoltaics (PV), biomass power, ocean energy and geothermal power.

The minimum RE portfolio targets are overachieved in both scenarios due to the demand for reduced carbon emissions and the technological progress making RE technologies cost competitive with other energy sources.

Table 5: Minimum RE portfolio modelling requirements in the two scenarios

Stated Policies	2030	2050
Wind	11%	16%
Solar	7%	10%
Bio	1%	2%
RE(incl. hydro)	39%	47%
Below 2°C	**2030**	**2050**
Wind	15%	22%
Solar	11%	15%
Bio	1%	2%
RE(incl.hydro)	46%	58%

Table 6: Resulting RE share of power generation in the two scenarios

Resulting RES hare Of Power Generation	2016	2020	2030	2040	2050
Stated Policies	16%	33%	51%	65%	78%
Below2°C	16%	45%	68%	80%	85%

Power Market and Grid Development

The ongoing process of power sector reform is assumed to have successful implementation in both scenarios. CREO modelling has included a gradual implementation of market principles in the power system dispatch, removing current market-constraints and adding coordination among local markets. Non-market-based power generation plans are discontinued, interprovincial transmission scheduling becomes market-based, and technologies which benefit from low market prices in situations with oversupply are introduced including electric boilers for district heating, air conditioner loads in buildings, industrial process demand shifts and smart charging of electric vehicles.

The lack of flexibility in the operation of interprovincial transmission is assumed to be relaxed over time. It is assumed that efficient trade develops and that markets will start to connect as arbitrage opportunities become apparent from increasing transparency in price setting. A gradual development towards an interconnected Chinese market is assumed and a fully harmonised market is assumed to be in place by 2040. Overall, it is assumed that the power market will become a decisive factor in the future development of the power system and the integration of renewable energy.

Scenario Results

RE Development Towards 2050

The CREO depicts two pathways for the development of the Chinese energy system through 2050. The Stated Policies Scenario keeps energy policies on the current path, while the Below 2 °C Scenario is driven by a strict carbon budget.

Renewable Energy Becomes Central

By 2016, the share of RE in the total energy supply reached 6%. China will maintain its position as the world's largest investor in RE, and the share of RE will grow immensely in the coming decades as a result of China's ambitious energy policies and the need to decarbonise the energy system.

In 2016 RE constituted 270 Mtce. Towards 2050 this increases eightfold in the Below 2 °C Scenario, where RE amounts to 2,186 Mtce compared to an increase to 1,663 Mtce in the Stated Policies Scenario. The major trend in the Below 2 °C Scenario is an initial expansion of wind power, followed by solar energy in the medium term towards 2035. In the long term towards 2050 solar energy expands and utilisation of biofuels develops rapidly. As there is limited potential for further development of hydro resources these follow the same incremental growth in both scenarios.

In the Below 2 °C Scenario renewable energy covers most of energy demand in 2050. Wind and solar power will grow rapidly until 2030, in the initial part of the energy transition.

Figure 7 RE share of primary energy demand in percent, calculated by the coal substitution method

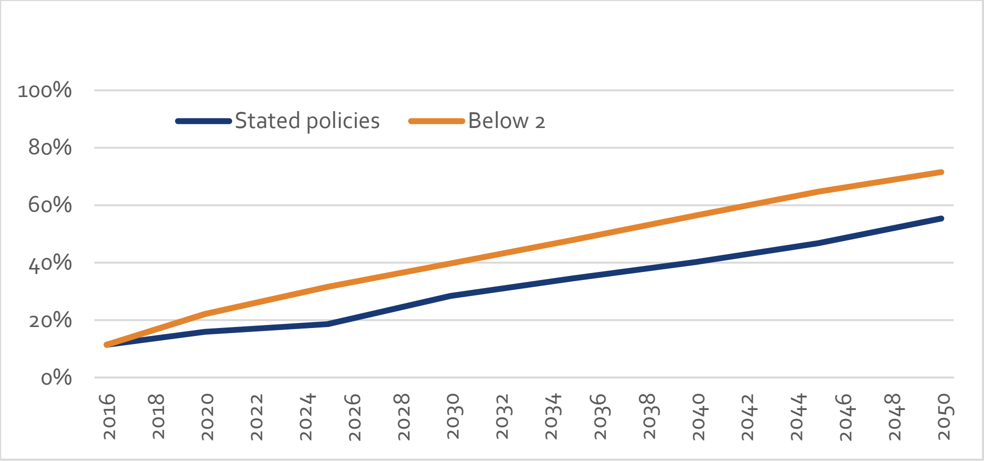
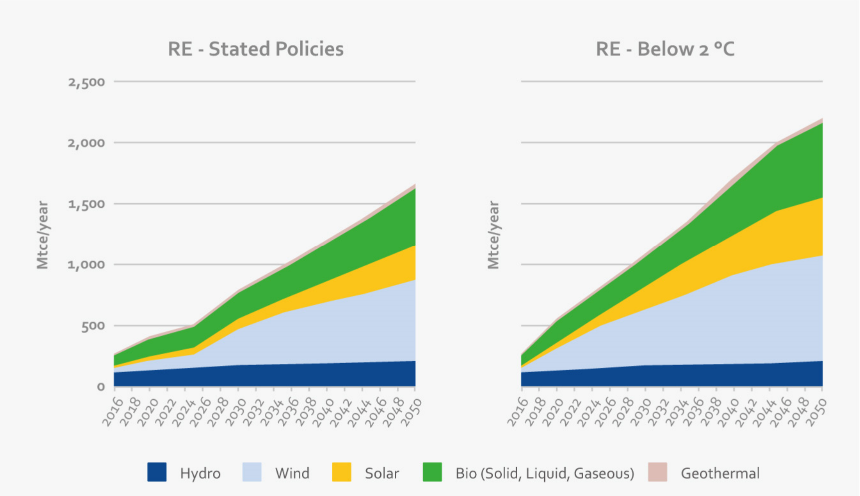


Figure 8 Energy production (Mtce) from renewable energy sources in the two main scenarios (2016-2050)



Supply and Demand

The energy demand will change considerably in the future. Today the industrial sector is dominant. In 2050 – while the total energy demand will be at the same level as today – the composition will change. The energy consumption in the industry sector will be much lower, while energy use in the transport and building sectors will grow.

The development of energy demand is characterised by a high degree of electrification and a shift to less energy-intensive industry. A collection of extensive energy efficiency measures is in place in both scenarios. This is the main reason the energy demand follows a similar trend in the two scenarios with a peak around 2030.

The Stated Policies Scenario projects a final energy demand of 3,530 Mtce in 2050. The energy demand development trend is similar in the two scenarios due to the assumed impact of energy efficiency measures.

The degree of electrification in the end-use sectors is substantial and most of this new demand is satisfied by renewable sources. This is true for both scenarios however the electrification and share of renewable energy is much higher in the Below 2 °C Scenario. In this scenario, 52% of energy demand is electricity in 2050, compared to 39% in the Stated Policies Scenario. The use of fossil energy in the industrial sector is largely replaced by electricity.

China is on the path to a greener and more diversified energy supply. The heavy reliance on coal is cut and replaced with non-fossil energy sources. This development is much more pronounced in the Below 2 °C Scenario where non-fossil energy makes up 63% of energy supply in 2050, compared to 47% in the Stated Policies Scenario (77% in the Below 2 °C

Scenario and 63% in the Stated Policies Scenario, if we use the coal substitution method). The rapid and decisive expansion of non-fossil energy in the Below 2 °C Scenario is the crux of China's strong contribution to achieving the targets of the Paris Agreement. In both scenarios the energy demand will peak around 2030 and by 2050 the Below 2 °C Scenario will have and energy demand of 3,321 Mtce.

Figure 9 Final energy demand (Mtce) in 2050 in the two scenarios compared with today, by sector and fuel type

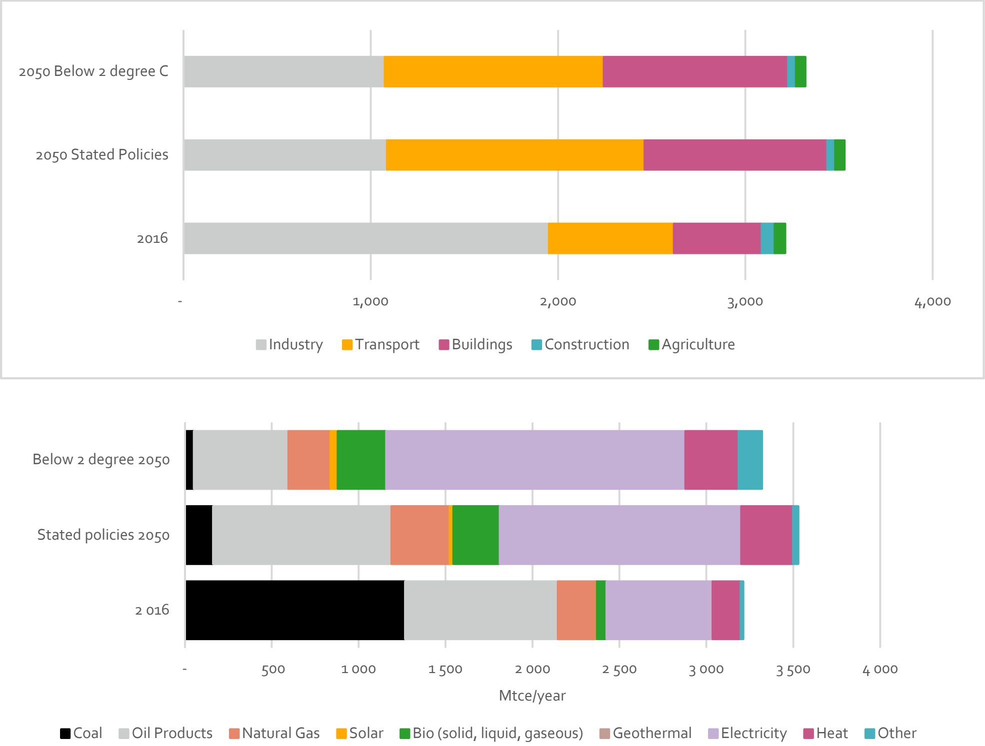
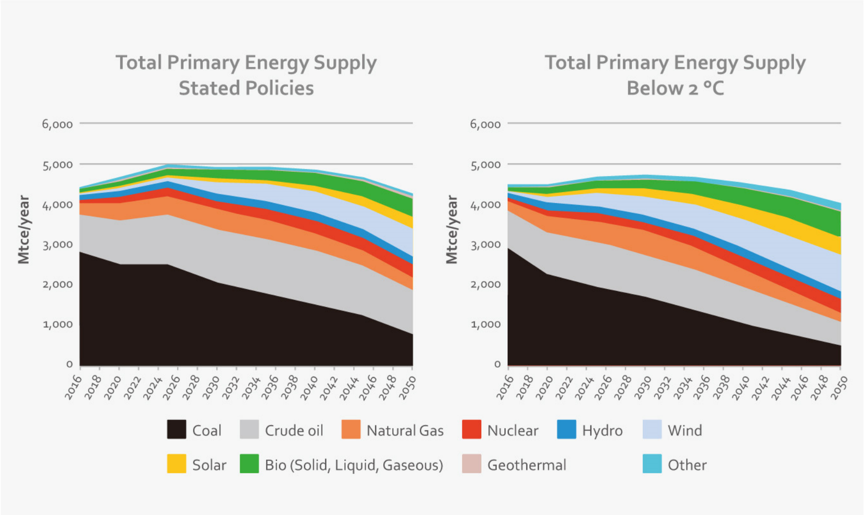


Figure 10 Development of the primary energy demand in the two scenarios (Mtce) 2016-2050, by fuel type



Environment – CO_2 Emission

Achieving Absolute Emission and Per Capita Emission Targets

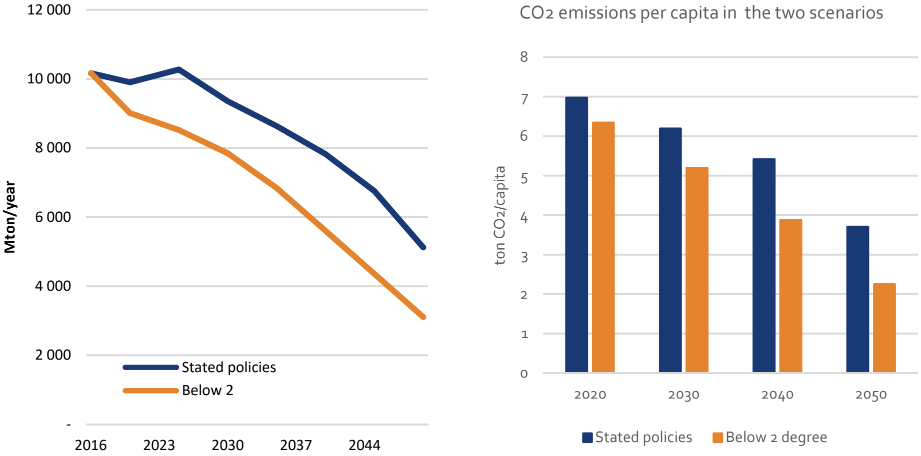
Cuts in fossil fuel consumption will successfully set the energy sector on a decarbonisation path. Swift short-term actions lead to initial CO_2 reductions, especially in the Below 2 °C Scenario where emissions from the energy sector have already peaked.

After initial reductions in the Stated Polices Scenario carbon emissions will increase slightly and peak in 2025. After 2025 the pace of CO_2 reductions is comparable with average annual reductions of 206 Mton in the Stated Policies Scenario and 216 Mton in the Below 2 °C Scenario over a 25-year period.

In the Below 2 °C Scenario initial ambitious actions and subsequent steady reductions provide significant long-term reductions with extensive societal benefits. This shows the importance of swift action to reach the carbon target. In the Stated Policies Scenario, the market will provide the necessary push for carbon reductions in the form of CO_2 pricing and cost competitive renewables in the long term, but on a short-term basis more ambitious policies are needed. In the Below 2 °C Scenario, which has the highest level of CO_2 emission reductions, the power sector will achieve the most substantial reductions. As population development is the same in the two scenarios, the per capita CO_2 emissions follow the same trend. Through restructuring of the Chinese economy and extensive energy efficiency efforts CO_2 intensity is decreased in both scenarios.

The energy intensity of the Chinese economy will be drastically reduced in both scenarios. Industry takes up a smaller and smaller part of Chinese energy demand. In the short term the 13th FYP target for reductions of energy consumption by unit of GDP is overachieved in both scenarios. In the Stated Policies Scenario energy intensity is reduced by 25% compared to 2015 levels, in the Below 2 °C Scenario this is 31% over the five-year period.

Figure 12 CO_2 reduction (Mton) and reduction per capita (Mton/capita) in the two scenarios (2016-2050)s



Grid and Transmission

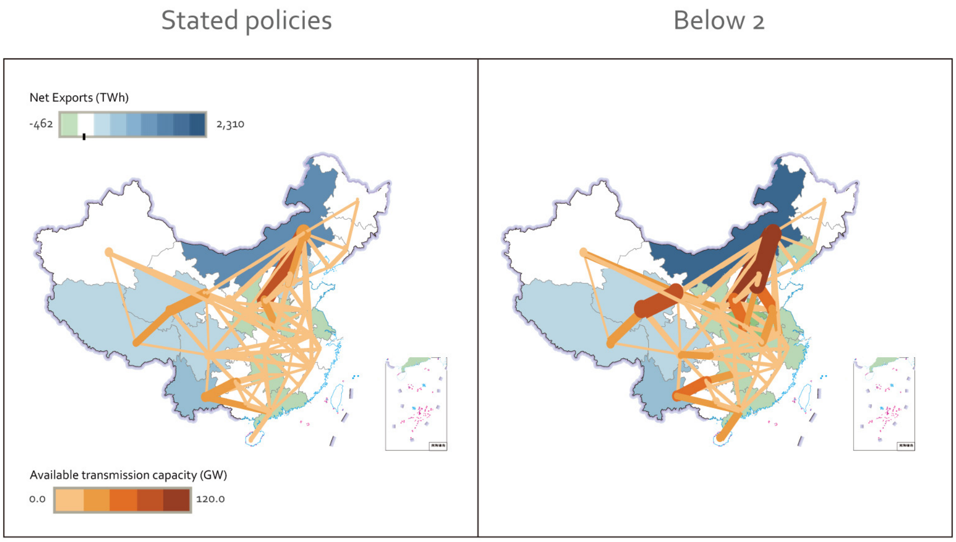
Both scenarios see extensive grid investments. Flexible use of the grid allows for clean electricity to be transmitted efficiently within as well as across regions. China's regional grids will be increasingly tightly integrated within larger balancing areas towards 2050 when the entire Chinese grid functions as one integrated market.

Most energy will be imported in the central and eastern provinces while south-western and north-eastern provinces will be net exporters.

The capacity expansion in the Below 2 °C Scenario is higher than the Stated Policies Scenario along all the interfaces, demonstrating the widely accepted premise that the higher the penetration of variable renewable energy, the higher the value of transmission capacity to smooth generation fluctuations over a larger balancing area.

By 2050 in both scenarios, the transmission system in China has been expanded and further interconnected. It is operated according to market principles, connecting supply and demand through continuously adjusted pricing mechanisms. This gives higher value to the significant investments in new grid capacity, as illustrated later in this Outlook.

Figure 13 The transmission system and the power flow (net export/net import) between the provinces in 2050 for the two scenarios


Stated policies

Below 2

Power System Balancing

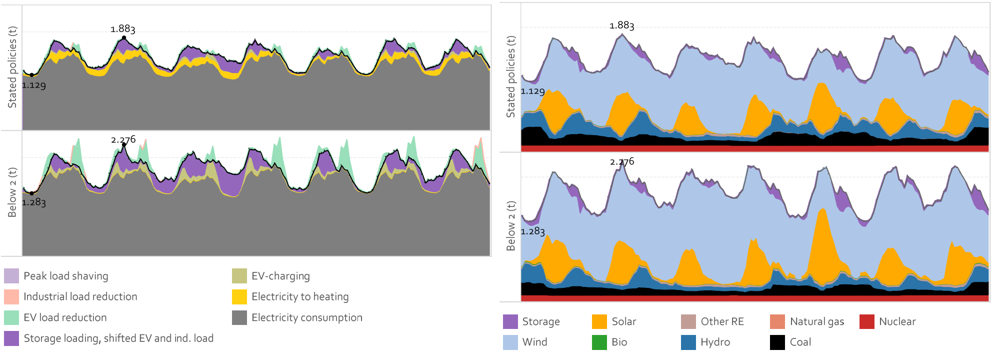
Wind can be the main source of electricity by 2030

Flexibility enables efficiency in a system with large shares of variable renewable energy. A wide set of comprehensive measures has been put in place to increase flexibility in power production, trade, and distribution as well as in energy end-use. The fleet of thermal power plants increases its flexibility, and through technological changes and market incentives the power plant's role in the system is transformed. Instead of contributing as a large base load, thermal power plants will function as a complement to variable renewable energy production. Already by 2020 a substantial fraction of coal plants will be retrofitted to allow for more flexible generation; this fraction is even higher in the Below 2 °C Scenario.

In the Below 2 °C Scenario wind becomes the major source of electricity by 2030. In addition to flexible transmission, demand response and storage technologies provide needed flexibility to balance the energy system. During peak load renewables provide more than 75% of power nationwide.

By 2050 the charging profile of electric vehicles will have a significant impact on the consumption patterns in both scenarios. Storage plays an important role in both scenarios as a flexible source to shift power around, and reshape consumption patterns. Coal power plays an active part in balancing the power supply and nuclear power continues to provide constant generation. Power from flexible combined heat and power plants (CHP) fuelled with biomass, combined with hydropower plants interplays with wind and solar generation to balance the system. Wind is the largest source in both scenarios in 2050. Solar becomes the second largest in Below 2 °C Scenario, producing more power than coal fired plants.

Figure 14 Hourly demand-side response and supply dispatch of the Chinese power system for one week in 2050 for the two scenarios



Power System Economics

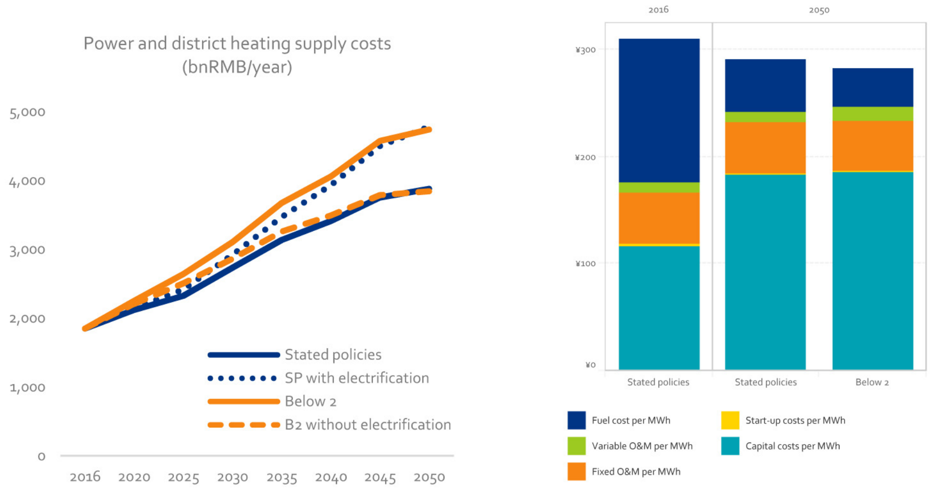
The system cost calculations only cover the power and district heating part of the energy sector. These are not directly comparable as the power and district heating demands differ greatly in the scenarios. To compare the power system cost of the two scenarios, the demand from one scenario is applied to the other. When using the same district heating and power demand in the two scenarios it becomes clear that the cost for the two scenarios is practically the same. This is before including external costs such as larger CO_2 emissions and climate change impacts, air pollution and associated health effects that highlight the benefits of the Below 2 °C Scenario. Capital costs will make up a larger share of electricity generation costs while fuel costs are reduced as more power is generated by wind and solar. This allows for low generation costs by 2050: 291 RMB/MWh in the Stated Policies Scenario and 282 RMB/MWh for the Below 2 °C Scenario (fixed price level).

Based on the RE development projected in CREO 2017, we further analysed the macro-economic impact of RE investments in the two scenarios using CNRECs Computable General Equilibrium (CGE) model.

The analyses show the investments in RE will effectively stimulate economic growth. The total investments in RE sector exceed 3.8 and 5.9 trillion RMB (2010 RMB) in 2050 under the Stated Policies and Below 2 °C scenarios respectively. In the Below 2 °C Scenario, RE investments account for 1% of total investment in the whole society and investments in wind and solar power generation reach 4.4 and 0.9 trillion RMB, respectively. The output value directly driven by the RE sector is expected to reach 12.6 trillion RMB and the total value added can reach 7.6 trillion RMB, with wind power generation constituting the majority.

More importantly, the analysis finds the development of the RE sector helps to shape a heathier economy, where sustainable industries such as power electronics, advanced materials, R&D, and others can be promoted. It also indicates that the government needs to prepare the transition for such industries as coal mining and transport where the labour force will need to be reduced quickly. This transition from old industries to new industries needs careful attention to minimize obstacles for the necessary energy transition process.

Figure 15 Total power system cost development (billion RMB/year) in the two scenarios 2016-2050, under different assumptions regarding electrification of the end-use sectors (left) and power system costs (RMB/MWh) for the two scenarios in 2050 compared to today's cost structure and level (right)



Policy Implementation Strategies

From Scenarios to Strategies to Implementation

Achieving the objectives of the Paris Agreement requires immediate global action to comply with the reduction targets and to avoid being trapped in the old energy infrastructures over the next decades. Also, China should quickly deploy a long-term energy transformation roadmap to translate the consensus about "Beautiful China" and "Below 2 Degree Targets" into concrete actions.

The "Energy Production and Consumption Revolution Strategy 2030", issued by the Chinese government, for the first time formally stated the long-term target that non-fossil energy should account for more than half of the energy consumption in 2050. Based on the recent rapid technological progress, international practical experience, and systematic scenario analyses, we show in the Below 2 °C Scenario that not only can China achieve its objectives, but also further enhance the 2050 renewable energy target to 54%. The measures to reach the more ambitious targets are changes in both the energy supply and energy demand, the development of energy system flexibility in all parts of the energy system, an efficient power market, institutional innovation, and change of mind-set.

China and the provinces (including autonomous regions and municipalities) should take a "top-down" approach to decompose the national targets and a "bottom-up" approach to promote renewable energy in various sectors and regions as an alternative to coal, oil and gas to seize the following opportunities: billions of kilowatts of renewable energy power generation and hundreds of millions of electric vehicles in co-operation; electrification of the high-polluting industries and urban and rural commercial consumers; urban and rural power and thermal gas base facilities expansion; and integration of distributed renewable energy, fully realizing the promise of the energy revolution.

China needs to further promote a comprehensive energy transition, market reform and reshaping of the energy system through regulation. China should strengthen the coordination of legislative amendments and speed up the introduction of an energy law and the revision of the power law, the implementation of the renewable energy law, the development of local laws and regulations. National and provincial energy system transformation paths should be established breaking down market barriers and launching a new round of electricity market reform. China should promote competition in the electricity market and establish integrated energy management with a professional supervision system serving to effectively promote and protect the green low-carbon energy transformation.

In the following we briefly highlight the main result from our policy research regarding the energy transition. The research is described in detail in the full CREO report.

Supporting Policy: From Incentives to Market Driven Deployment

In the short term before 2020, it is necessary to continue with the current feed-in tariff system for all RE technologies because no other system is in place. For new technologies, including offshore wind power and solar thermal power generation the support system should continue after 2020 to ensure a stable platform for development. However, China should make better use of competitive bidding to stimulate cost reductions for mature technologies, and gradually expand the scope and scale of competitive bidding to include new technologies.

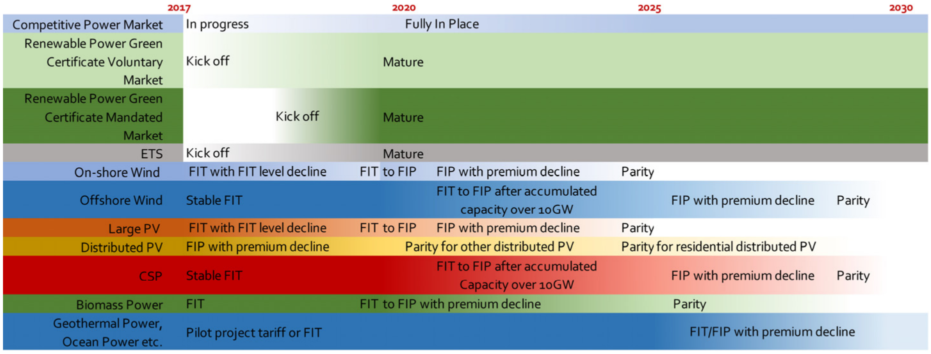
With the gradual establishment of competitive power markets after 2020, wind power and solar power should be integrated into the market, and the subsidy system should be linked with the electricity market price. As a start, the feed-in tariff could be replaced by a feed-in premium, and the premium should be frequently adjusted to reflect future cost reductions for the RE technologies. Different types of feed-in premium should be considered, including Contract for Differences and competitive bidding in combination with the market price.

Based on the establishment of a voluntary trading market for RE power certificates in 2017, a mandatory RE electricity quota and green certificate market should be established by 2020, increasing the quota requirement year by year to form a tradable green certificate price formation mechanism. The penalty for non-compliance should be increased year after year.

The national carbon trading market that will start in 2018 should play a major role in promoting fair competition between RE and fossil fuels.

Besides RE power, efficient mechanisms for promoting RE for heating must also be established. A quota system for RE in new buildings and for industrial RE heating should be considered.

Table 7: Roadmap for development of the subsidy system for RE technologies



	2017		2020	2025		2030
Competitive Power Market	In progress		Fully In Place			
Renewable Power Green Certificate Voluntary Market	Kick off		Mature			
Renewable Power Green Certificate Mandated Market		Kick off	Mature			
ETS	Kick off		Mature			
On-shore Wind	FIT with FIT level decline	FIT to FIP	FIP with premium decline	Parity		
Offshore Wind	Stable FIT		FIT to FIP after accumulated capacity over 10GW		FIP with premium decline	Parity
Large PV	FIT with FIT level decline	FIT to FIP	FIP with premium decline	Parity		
Distributed PV	FIP with premium decline		Parity for other distributed PV	Parity for residential distributed PV		
CSP	Stable FIT		FIT to FIP after accumulated Capacity over 10GW		FIP with premium decline	Parity
Biomass Power	FIT	FIT to FIP with premium decline		Parity		
Geothermal Power, Ocean Power etc.	Pilot project tariff or FIT				FIT/FIP with premium decline	

Power Market Design: Competitive Electricity Market with Increased Flexibility and Coordinated Incentive Policy

The modern power market, characterised by having a spot market, is the core of the institutional arrangement of power market reform. There are many effective power market models, but they all the follow the three basic principles of marginal pricing, opportunity cost pricing, and no arbitrage pricing. It is beneficial to fully exploit zero-marginal cost generation, realizing the lowest possible electricity system cost and thereby maximizing social welfare.

Presently, China's power sector is still mainly operated though planned allocation of generation (especially coal) and inter-provincial and cross-regional tie-lines are dispatched as base load units. Model simulations show that between 2016 and 2050, the persistence of these two factors mean an incremental system cost penalty of 1 trillion RMB. China needs to gradually replace the current planned dispatch and direct trade approach and develop a modern electricity market with a spot market at its core. China's first spot market pilot will start in 2018. In markets with high penetration of variable renewables, like wind and solar, the new power markets should be combined with forecasts from power producers and from the grid operator. The market should be developed first through the spot market and gradually into a real-time market as experience is accumulated.

Simultaneously, an ancillary service market should be developed rather than having an ancillary service compensation mechanism. How renewable energy can participate in the long-term, medium-term, and spot markets should gradually be explored.

The participation of new energy power generation in the electricity market still requires a low carbon policy framework to support its deployment. With zero-marginal cost, wind power and solar power become the dominant power sources, in many cases lowering the spot market price and creating a risk for new energy investments. New energy sources must therefore be incentivised to improve their output characteristics and their flexibility, enhancing their value in the power system and electricity market. The low-carbon policy framework should be updated to reflect its societal value either by 1) enabling the sale of tradable green certificates arising from mandatory renewable energy quotas, or 2) establishing a competitive bidding price for a feed-in premium on top of the spot price in the medium term and a Contract-for-Difference mechanism to hedge underlying price risk in the longer term.

Finally, a power market information disclosure system, including disclosure timetables, shall be established. This will promote transaction scheduling for agencies' provision of data including the state of load, supply, network, congestion, early warning messages, transaction volumes, price, and other information necessary to eliminate information barriers and asymmetries - all supporting fair and orderly competition.

Distributed Energy Systems: Strengthening Urban Responsibility and Open Sharing Mechanisms

The city level of administration should have the main responsibility for planning and construction of distributed energy systems. The "high RE share city" should carry out the detailed planning of the distributed energy integration into the city infrastructure. The distributed solar PV power generation, geothermal energy and heat pumps, hydrogen systems, energy storage and electric car charging systems, and micro-grids should effectively be integrated into city planning, transportation planning, ecological planning and other "multi-regulation" and "urban design" work, so that distributed energy becomes an integrated organic part of urban and rural life and economic production.

The urban infrastructure in form of power grids, district heating pipelines, and gas pipelines constitutes an excellent platform for integrating distributed energy systems and thereby allowing for an increased share of renewable energy in the city supply and increasing the consumers' economic benefit. To do this, the borders between the different energy sectors within the city level must be removed and cross-sectoral multi-energy integration and coordination of scheduling should be established. An integrated approach to electric heating, demand response load integration, electric vehicle intelligent charging and vehicle-to-grid integration, intelligent micro-networks and other complementary optimized technology applications should be promoted.

It should be easier to establish distributed energy systems, allowing for third-party access and shared solutions. This can be facilitated by establishment of appropriate energy management systems; simplifying distributed power generation project investment management and grid management procedures; reform and innovation of the urban heating and gas licensing system; and the establishment of renewable energy heat and gas third-party access rules. Furthermore, the establishment of urban thermal, gas and power network integrated planning and unified regulatory agencies to stimulate micro-grid and new distribution network investment management should be explored.

Distributed energy competitiveness should be promoted by developing suitable policies and market mechanisms. Renewable power and gas supply should be integrated with the network tariff. Implementation of RE quota system should be considered, along with development of an urban distribution network and gas and heat pipe network pricing mechanism. Also, the establishment of distribution network and microgrid power, heat and gas trading platform could reflect the real value of distributed energy's low net cost and high user value. Finally, to encourage distributed energy, electric vehicles and virtual power plants should be able to participate in the spot and auxiliary services markets.

Carbon Trading Market: From Affordable Price to Real Impact

The Chinese government has decided to introduce a carbon market to promote economic and social transformation to low-carbon energy system. To achieve the global "below 2 °C" target, carbon emission constraints become an increasingly important driving force for the development of renewable energy.

The three main ways a carbon market can influence the development of RE are: 1) increasing the cost of fossil energy consumption, changing the renewable energy and fossil energy comparative advantages; 2) giving RE projects credit for emission reductions, providing direct incentives; 3) providing revenue to support RE project financing, RE technology research and development, and RE-related infrastructure.

China's national carbon market is still in the preparatory stage, and in the early stage of the market it is not realistic or feasible to have a high carbon market price level. Timely consideration should be given to the introduction of a certified voluntary emission reduction mechanism with priority to expensive RE technologies like offshore power. While the carbon market continues to mature, the power industry can be the first to introduce a quota auction mechanism, and a certain percentage of auction revenue can support the development of RE related technology research and development and infrastructure construction.

With the gradual development of the carbon market, carbon emission reduction targets can be increasingly strengthened. The future of China's carbon market price is expected in 2030 to reach 200-300 RMB/t. Therefore, with the continuous decline in the cost of renewable energy technology, the carbon market is expected to become an important driving force for the energy system transformation.

Power Grid Development: Develop a Green and Service-Oriented Platform

China's future power grid development should focus on supporting the national economic development and the overall strategy for energy transformation. The future grid will activate advanced technology and adapt to a market-oriented operating mechanism. The development should support the coordination of power grids at all levels, allowing for flexible exchange of power from the provincial to the regional grid and then to the country through a layered scheduling mechanism, supporting intelligent use of the distribution network and distributed generation. Overall the future grid should be designed to optimise the allocation of energy resources and deliver a platform for green energy to meet the diverse needs of the users.

Towards 2022, power grid development should address the lack of coordination the power grid and power supplies, and improve distribution network construction as a priority task. All 34 provinces, municipalities, and autonomous regions should achieve the basic coverage of ultrahigh voltage (UHV) transmission network. Comprehensive development of the power grid should meet the needs of the provincial/regional/national three-level scheduling mechanism. The AC-DC UHV transmission lines will be used to deliver renewable energy-based power from western and northern China to eastern China, according to new urbanisation and development needs. By 2022 the transmission and distribution grid should be developed to a strong, reliable national network.

Towards 2030 the grid construction should focus on solving the problem of economic efficiency of the grid, and gradually break the barriers of interest between provinces, improve inter-provincial and inter-provincial power interdependence; actively serve renewable energy, distributed power, electric vehicles, and other diversified demand, to promote the optimal use of various types of resources.

Towards 2050 the Chinese grid should form a full power grid on all levels, full supporting flexible power exchange on inter-provincial power grids, ensure intelligent use of distribution network and act as a facilitator for renewable energy in a nation-wide free power market with high security of supply. The grid should not be a barrier for an economic efficient market driven dispatch of the large amount of renewable energy as a national resource.

JingJinJi: Green Development

Beijing-Tianjin-Hebei (the JingJinJi area) is China's "capital circle", one of the largest and most dynamic areas in Northern China. Rapid economic growth, the constant transformation of the industrial landscape and serious environmental pollution problems places high expectations on the Beijing-Tianjin-Hebei development towards a region with clean and secure energy system.

Today, the share of renewable energy is low, the diverse renewable energy resource potential is not utilised, and the power grid and infrastructure development is not synchronized. There is a strong need for a coordinated regional effort and for constant improvement in energy policy regulation and related institutional mechanisms.

Our research shows that JingJinJi can achieve a high share of renewable energy development as part of a comprehensive energy transformation. In the Below 2 °C Scenario, the installed capacity of wind power in 2030 reaches 128,165 MW, accounting for 47.8% of the total installed capacity. The total installed capacity of solar power reaches 83,922 MW, accounting for 31.3% of the total installed capacity. In the development of Xiong'an city, a new national area, RE could supply a 50% share of primary energy consumption by 2030.

In view of the high priority of renewable energy development in the JingJinJi region, the governments of Beijing-Tianjin-Hebei are encouraged to consider the following five actions: 1) strengthen the overall planning and design of renewable energy development, 2) improve the regional synergies regarding renewable energy, 3) increase the policy support to renewable energy, 4) develop innovative market mechanisms to promote renewable energy, and 5) increase public awareness of the benefits of a green energy transition.

Part 1:
Energy status and global trends

1 The global energy situation

1.1 Growing fossil fuel consumption and climate action

For the last 200 years, the world has been dependent on the use of fossil fuels for its economic development. Access to affordable energy has been one of the most important conditions for economic growth.

The burning of fossil fuels has also had undesired consequences. The "London Smog" in the 1950s, the smog problems in Los Angeles in the 1970s and the European acid rainsin the 1970s and the 1980s are examples of the effects of pollution from stoves, cars and power plants using coal or oil. Nevertheless, regions with filter technologies and bans on individual coal furnaces did reduce the air pollution problems in these areas.

In the 1970s the first and second "Oil Crises" revealed how dependent the world had become on cheap oil from a small number of countries. This resulted in the formation of the International Energy Agency, whose major and primary task was to set up and maintain plans to avoid oil shortages. It also paved the way for the first energy plans in several countries, where politicians wanted to move away from asevere dependency on oil. In Denmark, for example, the first energy plan emerged in 1976 with a focus on fuel diversification, energy efficiency measures, and research and development (R&D)into alternative energy sources, including renewable energy.

In the 1980s the impact of the use of fossil fuels on the global climate came under a renewed focus. In 1987, the World Commission on Environment and Development, the so-called Brundtland Commission, published the report "Our Common Future", introducing the concept of "sustainable development" to a broader audience and linking economic development with critical environmental issues. The Commission emphasized that a continuation of the rapid growth in fossil fuel consumption is not compatible with long-term sustainable development and that it will cause severe damage to the environment, locally and globally. This also included the risk of rising temperatures because of carbon dioxide (CO2)emissions resulting from the burning of fossil fuels.

As a follow-up of the Brundtland-report, the United Nations Conference on Environment and Development, UNCED, was held in Rio de Janeiro in 1992. In addition to adopting a comprehensive action plan for the 21st Century, Agenda 21, UNCED also was also the scene of signatures to the United Nations Framework Convention on Climate Change, concluded in a separate negotiation process earlier in 1992.

The UN Framework Convention on Climate Change was based on new scientific recognition of the climate change problem. The aims of the IPCC is to assess the scientific evidence-base relevant to anthropogenic climate change, the impacts of anthropogenic climate change, as well as options for adaptation and mitigation. The first assessment report from the IPCC was published in 1990, concluding that emissions resulting from human activities are substantially increasing atmospheric concentrations of greenhouse gases: CO2, methane, Chlorofluorocarbons (CFCs) and nitrous oxide. These increases will accentuate the greenhouse effect, resulting in additional, average, warming of the earth's surface. In response, the Danish government launched in 1990, the world's first energy action plan that aimed to reduce CO2 emissions from the energy sector.

Already in 1990 the Danish government launched the world's first energy action plan with a target for reduction of CO2 emissions from the energy sector.

The United Nations Sustainable Development Goals

Today, the climate change issue is one of the most important drivers for the radical transformation of global energy production and consumption the world's energy use. The 2015 United Nations Sustainable Development Goals from 2015 include targets for "Climate Action" as well as targets for "Affordable and Clean Energy". And all major international institutions responsible for working with energy system development have now integrated low-carbon principles into their work scenarios as integrated parts of their work.

The Paris Agreement on climate change

The Paris Agreement on climate change from December 2015 is the latest manifestation of the global determination to mitigate the impact of anthropogenic climate change.

The Paris Agreement sets out acommon goal to limit global warming and identifies ways in which this might be achieved. It aims to strengthen the global response to the threat of climate change by

> *"Holding the increase in the global average temperature to well below 2 °C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5 °C above pre-industrial levels."*

Countries are committed to reach this goal via "global peaking of greenhouse-gas emissions as soon as possible", recognising that this will take longer for developing countries. Subsequently reducing emissions rapidly to a level, sometime in the second-half of this century, when the world achieves a balance between anthropogenic emissions and their removal from the atmosphere by sinks[1].

Renewable Energy Action plan of G20

The Group of Twenty (G20)[2] represents more than 80% of global primary energy consumption and 80% of greenhouse gas (GHG) emissions; it includes the world's largest energy producers and consumers.[3]As a block, the G20 there foreoccupies a key position in global efforts to reduce the climate impact of the energy sector. According to estimates by the International Renewable Energy Agency (IRENA), G20 countries are home to 80% of the world's total installed renewable power generation capacity. They also represent 75% of global deployment potential in energy sector renewable energy between 2010 and 2030.[4]

Energy, and its link to climate change is a prominent feature of this year's German G20 presidency and was equally so under China's agenda in 2016. G20 members acknowledge the urgent need to promote sustainable development and action to prevent anthropogenic climate change by stepping up the transformation of their energy sectors.

At the 2016 Hangzhou G20 Summit, leaders endorsed the "G20 Voluntary Collaboration Action Plan on Energy Access", the "G20 Voluntary Action Plan on Renewable Energy and the G20 Energy Efficiency Leading Programme", emphasizing the role of energy for sustainable economic development and poverty alleviation, and the importance of energy efficiency and renewable energy for shaping an affordable, reliable, sustainable, cleaner and low GHG emissions energy future.

At the G20 Summit in Hamburg in July 2017, leaders stressed the interdependence between economic development and ecology, and reiterated the key role of the energy sector for reducing GHG emissions, noting that a "strong economy and a healthy planet are mutually reinforcing."[5]Members also endorsed the notion the transition to low-carbon energy systems presents opportunities for innovation, sustainable growth, competitiveness, and job creation. And in turn, generating good prospects for the low-carbon modernisation of the economy. The "G20 Hamburg Climate and Energy Action Plan for Growth" endorsed by G20 leaders highlighted "robust, long-term energy sector development strategies" as an effective tool to increase investor certainty, guide the

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[1] IEA WEO 2016 page 36

[2] The Group of Twenty (G20) is comprised of 19 countries plus the European Union. The countries are Argentina, Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, Mexico, Russia, Saudi Arabia, South Africa, South Korea, Turkey, the United Kingdom and the United States of America.

[3] G20 Energy Efficiency Leading Programme, G20, June 2016, p. 5

[4] G20 Voluntary Action Plan on Renewable Energy, G20, June 2016, p. 2

[5] G20 Leaders´ Declaration: Shaping an Interconnected World, G20, July 2017, p. 9

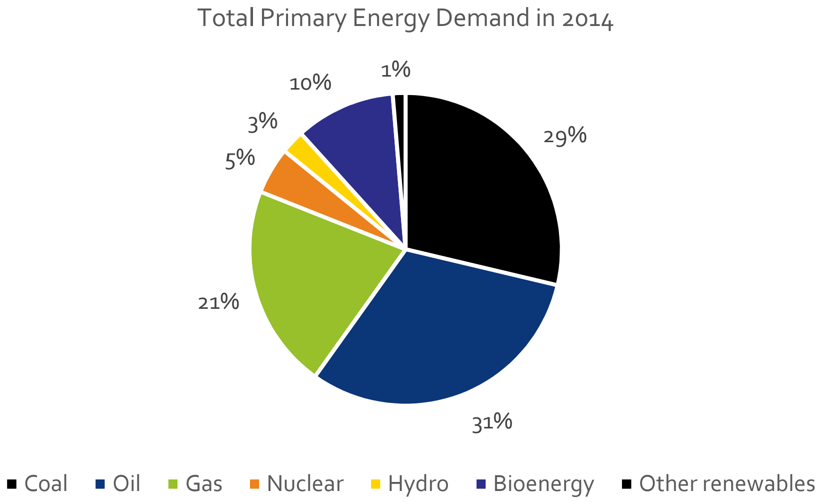
transformative change of economies and energy systems, and help minimise the risk of stranded assets in carbon-intensive industries.[6] In addition, the Action Plan highlighted need to redirect investment flows from fossil fuels to sustainable energy sources such as renewable energies and energy efficiency, and to create an investment environment conducive to the deployment of low-carbon technologies. For example, by phasing out inefficient fossil fuel subsidies that encourage wasteful consumption.

Shortly before the Hamburg Summit, the United States of America announced its decision to withdraw from the Paris Agreement. However, leaders of the other G20 members, including China, expressed their strong commitment to the Paris Agreement and its swift implementation, and stated that it was irreversible, thereby giving a strong political signal to the international community.

1.2 Fossil fuel still lead the global energy supply structure

Today the global energy supply is still heavily dependent on fossil fuels. In 2014, 60% of the total primary energy supply was covered by coal and oil and around 21% was covered by natural gas.

Figure1-1 The world's primary energy demand in 2014, divided by fuels.



Source World Energy Outlook 2016, IEA

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[6] Annex to G20 Leaders Declaration: G20 Hamburg Climate and Energy Action Plan for Growth, July 2017, p. 3

Global energy consumption and production is changing rapidly. Investments in the energy sector are shifting from fossil fuels to low-carbon technologies, energy efficiency and power grids[7]. The cost of renewable energy has fallen fast, making investments in these technologies competitive with fossil fuels in many countries. Moving away from the dominant use of fossil fuels in energy systems around the world is fundamental to limit global warming. Renewable energy technologies are now the fastest growing source of energy. Global energy demand is expected to continue to grow, however this will be at a slower rate as energy will be used more efficiently. Restructuring energy systems to promote efficiency and diversification requires fundamental changes in how systems are regulated and operated.

1.3 Energy Transition targets and actions – main institutions' outlook on renewable energy development (2030,2050)

Consensus already formed on renewable energy as a key driver of the global energy transition

A broad range of international organizations, energy research institutes and energy companies, including the World Energy Council (WEC), the International Energy Agency (IEA), IRENA, the Energy Information Administration (EIA), Exxon Mobil, BP and Bloomberg New Energy Finance, among others, have produced forecasts of global energy and low carbon energy technology development. They have also surveyed conventional energy enterprise viewpoints and medium to long-term (2040-2050) market forecasts on the same topic.

Table 1-1 summarizes the medium-to-long-term energy outlook of across a range of institutions.

Title	Organization	Publication Date	Outlook Time Scale	Organization Type
World Energy Scenarios 2016 – The Grand Transition	WEC	2016. 10	2060	International energy organization
World Energy Outlook 2016	IEA	2016. 11	2040	International energy organization
Energy Technology Perspectives 2017	IEA	2017. 06	2050	International energy organization
Perspectives for the Energy Transition 2017	IEA / IRENA	2017. 03	2030/2050	International energy organization

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[7] Source: Perspectives for the Energy Transition: Investment Needs for a Low Carbon Energy System, IEA and IRENA, March 2017

International Energy Outlook 2016	EIA	2016. 05	2040	National energy organization
Energy Outlook: A View of 2040	Exxon Mobil	2016. 12	2025/2040	Conventional energy enterprise
BP World Energy Outlook 2017	BP	2017. 07	2035/2050	Conventional energy enterprise
New Energy Outlook 2017	BNEF	2017. 06	2040	Consulting firm

While the objectives, research methodologies and target audience of these studies vary, they can all be placed under one of two labels: investor-focused, or decision-maker focused.

Investor-focused research primarily makes predictions of the future based on current realities and is generally intended to serve the needs of energy industry managers and analysts to make accurate forecasts about market development and operation cycles. The analytical reports by the EIA, ExxonMobil and BP fall into this category. The outlooks in this category all concluded that renewable energy will continue to grow consistently over the coming several decades, although this is unlikely to lead to drastic changes in the energy structure. Fossil-fuels will remain the primary energy form, not to be exceeded by renewable energies.

Decision-maker focused outlooks stand in contrast to this perspective. These aim to make **a retrospective analysis at a future time** – making forecasts at a future point in time, based on socio-economic development goals and energy/environmental development targets, or constraints. The outcomes of these studies represent a pathway to achieve the intended goals, using a reversed research methodology from a decision-maker's perspective. Examples of these include the forecasts produced by the IEA, WEO and IRENA, such as "REMap". In scenario modeling, the outcome energy structure under a retrospective scenario is fundamentally different from that under a predictive scenario. In these reports, results indicate that the consumption of renewable energy will surpass that of fossil-based energy. Retrospective scenarios in several studies all indicate that renewable energy's share in primary energy is expected to reach 30-45% in 2035 or 2040, and further to 50-70% in 2050.

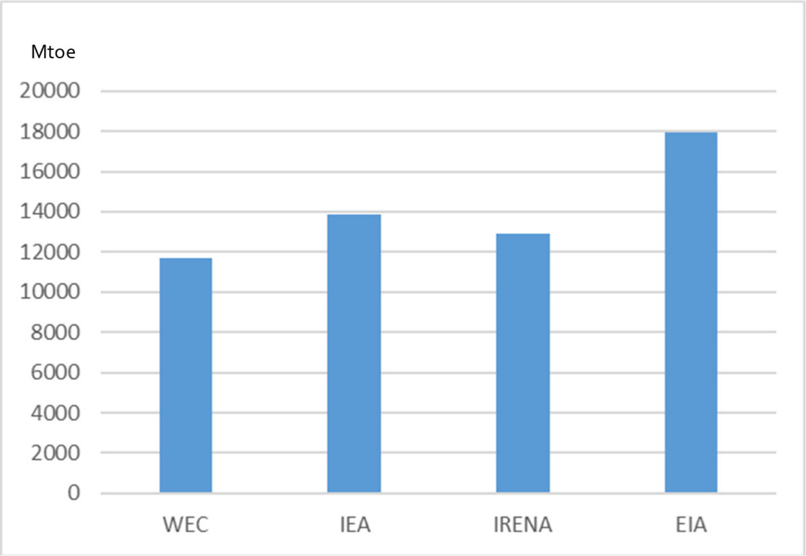
1.4 Conclusions on the global low-carbon transition

Despite significant differences in the final targets and implementation pathways for the future global energy transition, the outlooks listed above share some important similarities. First, global energy demand will level off. Second, on overall direction, global efforts to curb emissions will continue, and non-conventional fossil fuelswill diversify and continue to grow in their share of the energy system. Third, huge investments and efforts are needed for holding the increase in global average temperature below 2 degrees Celsius. In addition, a comparison of outlooks from the same institution over the past several years reveals a similar trend: projections for total energy consumption are getting lower, while projections of renewable energy's share of primary energy consumption are rising. A further common theme is the expectation that this rising share will contribute to cost reduction in renewable energy and other low carbon technologies, as well as growing investment.

(1) Future global energy growth tends to level off.

According to WEC, the combination of new technologies yielding higher energy efficiency and more stringent energy policies, will deliver a levelling off, and a peak in global primary energy consumption before 2030.Under three energy scenarios, final energy consumption will grow by 22-46% in 2060, whereas primary energy consumption merely grows by 10-34%. Primary energy consumption will peak in 2030 at approximately 1. 9toe per capita.

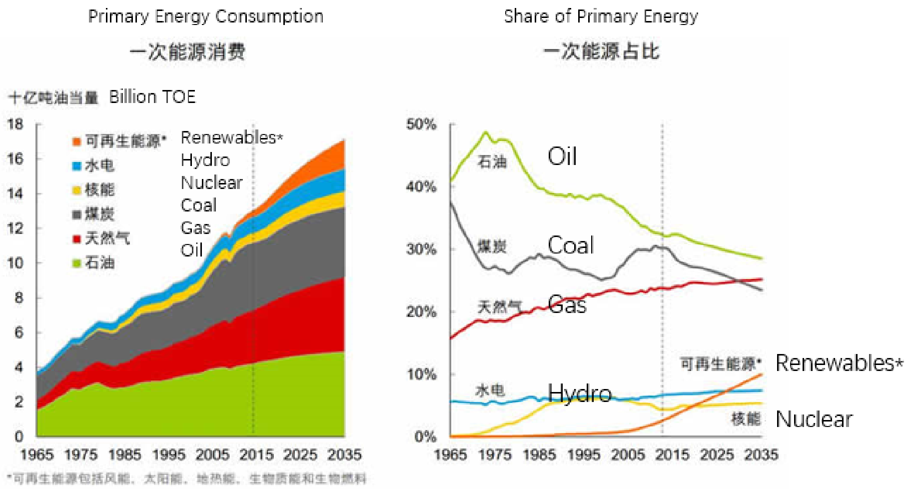
Figure 1-2 Total global energy demands in 2030



The IEA's central scenario projects that by 2040, global energy demand is expected to increase by 30%, suggesting demand will grow for all modern fuels. Nonetheless, this global macro projection overlooks tendencies in different regions, where major changes in fuel substitution will yield greatly different transition outcomes. Despite growing demand, the scenario suggests that there may still be approximately 100 million people without energy access in 2040.

In BP's 2017 Energy Outlook global energy demand is expected to grow by 30% between 2015 and 2035, an annual average of 1.3%. The BP's Outlook also predicts that renewable energy will grow fastest, at an annual average of 7. 1% per year. Renewables, nuclear and hydropower are expected to account for more than one half of growth in energy supply in the coming two decades.

Figure 1-3 Projected global primary energy consumption and share of sources in primary energy consumption.



*可再生能源包括风能、太阳能、地热能、生物质能和生物燃料

*Renewables include wind, solar, geothermal, biomass energy and biofuel.

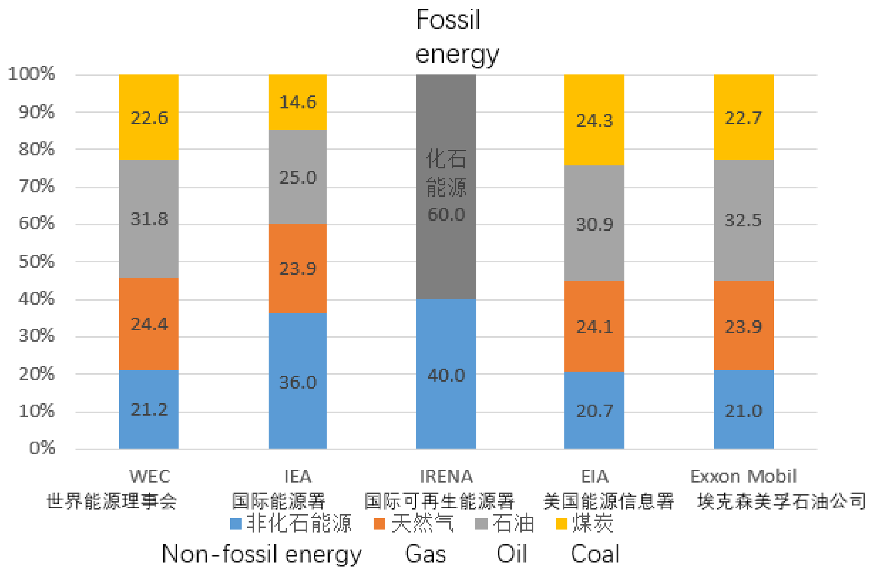
Data source: The BP Energy Outlook (2017 Edition)

According to the EIA's Annual Energy Outlook 2016, global energy consumption will grow by 48% between 2012 and 2040.Of all energy sources, coal will witness the slowest growth in global consumption, at merely 0.6% per year by 2040. Renewable energy and nuclear power will experience the most rapid growth in consumption, at 2.6% and 2.3% respectively, on an annual basis out to 2040.

ExxonMobil outlines significant possible improvements energy efficiency that may help to reduce energy consumption. In their projection, global energy demand will grow by 25% between 2014 and 2040. While energy demand in non-OECD countries will increase by 45%, ExxonMobil expects demand in OECD countries will remain low.

(2) Electricity will play an increasingly important role in the energy system, and energy sources will undergo diversification.

Figure 1-4: Consumption structure of primary energy source by type in 2030



The WEC expects electricity demand to double by 2060. This will require huge investment in infrastructure and system integration, to meet the needs of low carbon electricity. By 2060, electricity as a share of final energy consumption under three proposed scenarios will reach 25-29%. Fossil fuel as a share of primary energy consumption will drop to 50-70%. Oil and coal are expected to peak between 2030 and 2040.

The IEA also predicts that electricity will make up a larger share of the growth in final energy consumption, from a quarter in the past 25 years to 40%,according to the central scenario. Growth in demand for power will largely be met by growth in renewable and nuclear energy. On the demand side, innovations in transportation technology, electric vehicles in particular, will bolster electricity demand. Rising living standards means more electric appliances, equipment and other power-consuming products, and consequently, additional demand for electricity. By 2035, electricity from renewable energy sources (including hydropower) will account for one half of the growth in global power generation. Its share in total global power generation is expected to rise to 31%. Renewable energy will become the most important fuel for the power industry. Under the central scenario, by 2040, the number of electric vehicles will surpass 150 million, which corresponds to a reduction of 1. 3 million barrels of crude oil per day and hence reduces our reliance on oil. Under the ideal scenario, by 2040, there will be 715 million electric vehicles on the road, capable of substituting 6.0 million barrels of oil per day.

The EIA projects that by 2040, the share of fossil fuels in the global energy supply will remain high, over three quarters of the total. Of all fossil fuels, the share of natural gas will see the fastest capacity growth. Influenced by China's transition from highly energy-intensive industries to service industries and global coal-limiting policies, coal consumption is expected to cease growth in the medium term. By 2030, natural gas will surpass coal as the world's largest source of fuel for energy supply. By 2040, a balance is expected to be achieved in the global energy supply between coal, natural gas and renewable energy sources, with each at approximately 28-29% of global power generation.

BP claims the rise of unconventional hydrocarbon resources, such asshale oil and gas, multipolarization and diversification has become the norm for energy supply. The most notable change is the "Shale Gas Revolution" in the United States. Due to its influence, rich oil and gas resources in some American countries, such as the United States, Canada, Brazil and Venezuela, are now being utilized. As unconventional hydrocarbon resources develop and grow stronger, the American region is expected to become a "Second Middle East".

According to ExxonMobil, by 2040, oil and natural gas will account for nearly 60% of global energy supply, while nuclear and renewable energy accounts for nearly 25%. Driven by technological change, new energy sources will arise. It is predicted that oil, natural gas and coal will continue to meet 80% of global demand. As these resources are currently abundant, reliable and affordable, they are sufficient to meet the daily demands of 7 billion people worldwide. But, significant changes are imminent. Natural gas is expected to see the highest growth and broader application, due to its notable cost advantages. During this stage, renewable and nuclear energy are also expected to witness significant increases.

According to Bloomberg's 2017 New Energy Outlook, electric vehicles will not only support electricity demand but also help balance power grid load. By 2040, electricity demand attributed to electric vehicles will account for 13% and 12% of European and U. S. power consumption, respectively.

(3) Reducing carbon emissions requires global coordination and a concerted effort from all the parties involved; holding the increase in global average temperature below 2 degrees Celsius still remains a significant challenge.

The WEC expects carbon emissions to peak during 2020-2040. Achieving the goal of holding the increase in global average temperature below 2 degrees Celsius will require significant and consistent efforts, which willlikely entail very high carbon prices.

IEA: The Paris Agreement on climate change took effect as of November 2016. At the core of this Agreement is the issue of energy. The targets set out in its Declaration, that signatory countries must achieve, provide guidance on mitigating energy-related carbon dioxide emissions. However, they still fall short of the cuts required to keep global average temperatures from rising to 2 degrees Celsius. More ambitious decarbonisation targets and reducing levels of emissions, especially in relation to the power sector and fuel conversion, have become a matter of crucial importance to realizing carbon balance by the energy sector in 2060. We must develop new technologies, expand the application scope of sustainable bioenergy and carbon capture and storage technology, and drive technology costs down in order to meet the challenge of emissions reduction.

EIA: in the context of current policies and regulations, energy-related carbon dioxide emissions worldwide are expected to rise from 32 billion tons in 2012 to 36 billion tons in 2020, and further to 43 billion tons in 2040, at a growth rate of 34%.

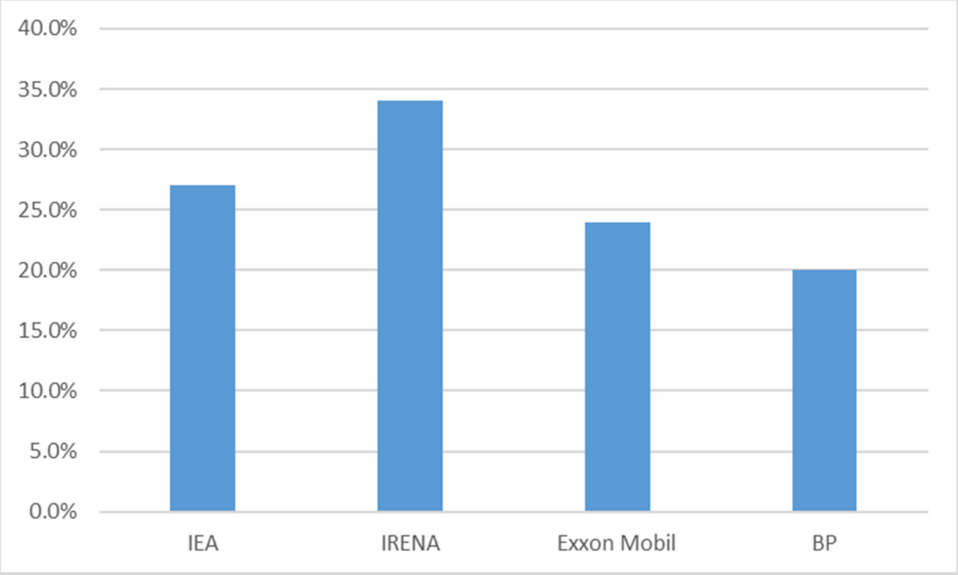
BP projects that carbon emissions will grow at an annual rate of 1% out to 2035. This is despite a reduction in carbon emission growth from 2.5% to 0.7%the past decade. Emissions growth therefore is expected to remain significantly higher that scientists' proposed growth trajectory. For example, carbon emissions in2035 will be 18 billion tons greater than the number assumed under IEA's 450 scenario (which is underpinned by limiting concentrations of GHGs in the atmosphere under the level of 450ppm CO2 equivalent).

ExxonMobil's Outlook for Energy: The Outlook's2040 scenario suggests thatenergy-related carbon dioxide emissions per unit of GDP will drop by 50%. This will be thanks to continuous, significant energy efficiency improvements and the deployment of low-carbon energy. Energy-related carbon dioxide emissions are expected to peak in 2030 and start to decline afterwards. In China, with greater low-carbon energy deployment, its carbon emissions will also peak gradually.

Bloomberg New Energy Finance (BNEF) projects that the decarbonisation process of the global power system will happy much sooner than originally anticipated. Carbon emissions worldwide are going to peak in 2026.Carbon emissions in 2040 will be 4% below the level in 2016. Global emissions from power generation are expected to peak in a decade or so and start to decline afterward. Global carbon dioxide emissions from the power sector will continue to rise before reaching a peak in 2026, and will then start to decline at a much faster pace than previously anticipated. Overall, global emissions in 2040 being 4% lower than in 2016 is still substantially above the cuts needed to meet the goal of holding the increase in global average temperature below 2 degrees Celsius. In fact, BNEF projects that achieving the target will require an additional investment of 5.3 trillion dollars to installa total of 3.9 TW in zero-carbon power generation capacity.

(4) Costs of renewable energy technologies are to decline significantly, with their shares in the energy system significantly rising.

Figure 1-5 Share of renewable energy in total global energy demand in 2030



WEC: Wind and solar energy will continue to grow rapidly. This will create both opportunities and challenges for the energy system. Renewable energy technologies, in particular wind and solar, are expected to see a cost reduction of 70% by 2060. By 2060, solar energy will make up 20-39% of total power generation. Large-scale energy storage technology will be widely deployed to cope with the development of variable distributed energy resources. Wind and solar PV power will account for at least 20% of energy consumption.

IEA: Reducing emissions in the power sectoris a core commitment made by many signatories of the Paris Agreement. Under the central scenario, by 2040, approximately 60% of power will be generated from renewable energy sources, nearly half of which are made up of wind and solar energy. In addition, power generation from many renewable energy resources will be competitive without subsidies. However, despite renewable energy cost reduction, they are barely sufficient to meet the demand for efficient, low-carbon power supply. Integration of wind and solar energy through power system design and operations, in combination with R&D investment, are essential.

BNEF's 2017 New Energy Outlook pointed out that by 2040, costs of solar and onshore wind power generation will further decline by 66% and 47%, respectively, and that power plants using renewable energy are expected to see larger reduction in operational costs than most of those using fossil fuels. By 2040, wind and solar energy will account for 48%

and 34%, respectively, of total installed generation capacity worldwide. This will represent significant growth from their present levels of 12% (wind) and 5% (solar) levels. New, flexible, capacity such as batteries will support renewable energy development. Residential, commercial and industrial small scale solar and energy storage systems will account for 57% of total global energy storage capacity before 2040. It is expected that by 2040, renewable energy penetration rates will reach 74%, 38%, 55% and 49%, respectively, in Germany, the US, China and India.

(5) Energy revolution needs global cooperation, continuous economic growth and persistent technological innovation.

From early-stage research, across-the-board demonstration through deployment, all innovation activities calls for support. Transitioning to new energy system requires not only progressive but also "great leap forward" style innovation. National government plays an important role, ensuring predictable, long-term support for innovation during all stages from basic and application research through development, demonstration and deployment stages. In order to achieve global climate goals, those technologies that are currently being in the innovation stage especially need robust policy support. This requires continuous growth of the global economy so that it may provide impetus to development of various technologies and industries.

The ongoing energy system transformation is reflected in the most recent global energy system scenarios. In the IEA World Energy Outlook 2016, the "450 ppm Scenario" reflects the current trends for energy system transformation towards a more sustainable, low-carbon energy system. In this scenario, renewable energy is expected in 2040 to cover 58% of the electricity demand, 22% of the heat demand and 20% of the transport energy demand - a significantly higher share than in the current energy system. The use of coal without Carbon Capture and Storage (CCS) in the power sector is reduced to 1/4 of today's consumption, and the CO2 emissions in 2040 are on the level of the emissions in 1990 with a peak before 2020.

This ambitious energy system transformation is however not sufficient to comply with the Paris Agreement's goals to limit the temperature rise to "well below 2 degrees Celsius". In the joint IEA and IRENA report "Perspectives for the Energy Transition: Investment Needs for a Low Carbon Energy System", a study initiated by the German Government to inform G20 work on energy and climate in the context of the 2017 German G20 presidency, the two organizations introduce a new global scenario, the "66% 2-degree C Scenario" to showcase the need for an energy transition, which would be able to fulfil the requirements in the Paris Climate Agreement. The key messages from such a scenario of limiting the global mean temperature rise to below 2 degrees Celsius with a probability of 66% are[8]:

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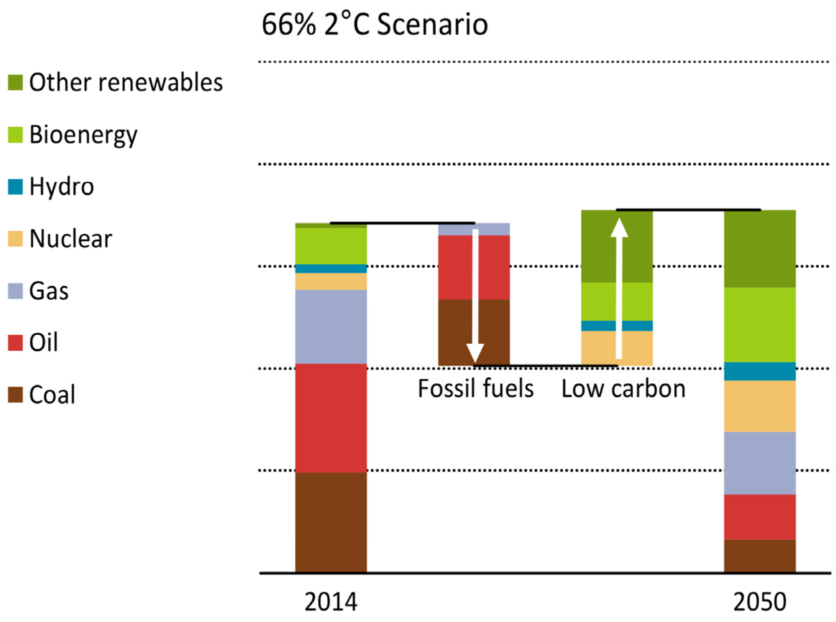
[8] Perspectives for the Energy Transition: Investment Needs for a Low Carbon Energy System, IEA and IRENA, March 2017, page 51-52

- To reach the targets in the Paris agreement would require an energy transition of exceptional scope, depth and speed, with an unparalleled ramp up of all low-carbon technologies in all countries.
- By 2050, nearly 95% of electricity would be low-carbon, 70% of new cars would be electric, the entire existing building stock would have been retrofitted, and the CO2 intensity of the industrial sector would be 80% lower than today.
- Coal use would decline rapidly, oil consumption would fall, and natural gas would play an important role in the transition across several end-use sectors.
- Early, concerted and consistent policy action would be imperative to facilitate the energy transition.
- It would be possible to achieve universal access to energy for all, while drastically improving air quality and cutting household energy expenditures.

The total energy consumption in 2050 in the 66% 2 °C Scenario is on the same level as today, and fossil fuels are partly replaced with low-carbon technologies.

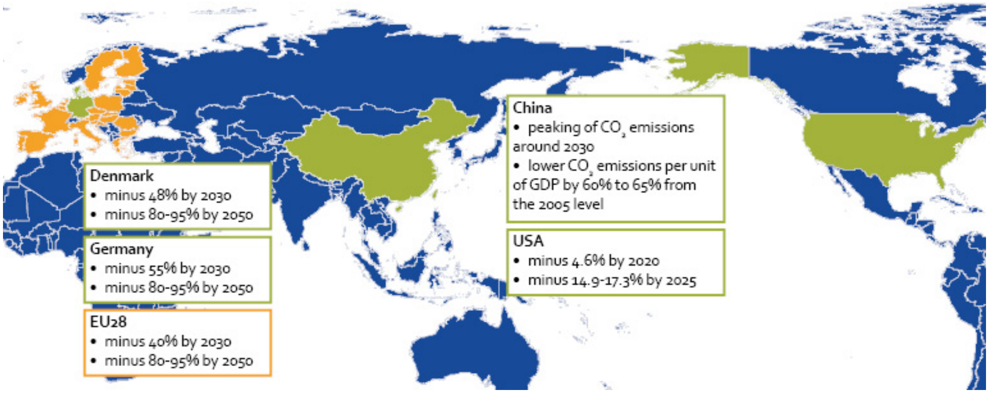


The scenarios in the IEA and IRENA reports are the backdrop for the national actions for energy transition. Several countries have acted towards a more sustainable, low-carbon energy system to fulfil the Paris Agreement. The quest is challenging and the implementation strategies are different for different countries. In the following chapter, we present the efforts made by some of the global frontrunner countries and regions to see what can be learnt for the Chinese context.

2 International trends in energy transition

Global warming affects all countries and can only be tackled in a conjoint international effort. The Paris agreement is considered to be a crucial milestone in the fight against climate change. For the first time virtually all countries worldwide acknowledged that the threat of global warming is real and commonly agreed on "holding the increase in the global average temperature to well below 2 °C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5 °C above pre-industrial levels." More and more countries have published their national GHG reduction targets in order to reach this goal.

Figure 2-1 Overview of key countries' GHG reduction targets[9]



In addition, in the past years many countries have initiated a transition of their energy systems towards a more sustainable energy supply based on renewable energies. The paths these countries have undertaken vary and depend on a number of variables, e.g., on their baseline energy system, their economic status, their geographical location or their political and societal setting. The following case studies shall illustrate this variety.

The European Union, with its enormous markets and infrastructure connectivity, is a leading global player and a strong advocate for the fight against climate change. Germany as one of Europe's biggest and most populated countries is a particularly good example of a highly industrialised nation that aims at decarbonising its economy. Denmark is widely considered a pioneer when it comes to renewable energies, particularly wind energy, and

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[9] The data shown in the graphic are based on either Nationally Determined Contributions (NDCs) submitted to the United Nations (UN) or, in the case of Denmark and Germany, additional national targets. Unless stated otherwise, the base year for all targets is 1990. In order to allow for comparability, for the U.S., official NDC targets with base year 2005 have been converted to a base year 1990 using data from theEnvironmental Protection Agency (EPA).The Danish GHG reduction target for 2030 is based upon the preliminary Danish non-ETS reduction target of 39% compared tothe 2005 level and is not an official Danish target. Denmark does not have an overall national target for reduction in 2030.

the transition of their electricity and heating systems. And the United States of America (USA), as a vast territorial state with an energy system dynamic driven by a strong market orientation and political complexities, sets another example for the wide variety of ongoing energy transitions.

What they all have in common is their experience that they 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 (wind, solar, biomass, etc.). This requires that policies and regulation reflect a clear long-term vision, with elaborated and regularly revised mid-term targets and continuous concrete adjustment steps on a short-term basis.

2.1 European Union

Main drivers for a European energy transition

In order to reach global climate protection targets, a reduction in carbon emissions is urgently needed. 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. An EU-wide energy system transition, i.e. implementing common targeted policies and advancing the structural integration of the EU are seen as important key drivers for the decarbonization of the economy.

Besides the decarbonization of its economy two other important goals are pursued with the EU energy policies: first, increasing the share of renewable energies while also increasing energy efficiency. This aims at reducing the EU's dependency on energy imports. Currently, energy imports make up for more than 50% of total energy consumption in the EU. Second, considering the global need for a clean energy supply the development of new technologies for a sustainable energy system is seen as a new strategic source of growth and employment.

The EU's long-term energy targets for 2030/2050

The long-term goal of reducing GHG emissions by 80-95% by 2050 compared to 1990 levels was set in October 2009 by the European Council. In December 2011, the EU published the Energy Roadmap 2050. At the Paris conference the EU represented all Member States with one voice. In March 2015, the EU as the first major economic zone, submitted its Intended Nationally Determined Contributions (INDCs) to the international agreement confirming its commitment to significantly reduce GHG emissions.

In October 2014, the European Council agreed to more concrete, EU-wide targets and policy objectives for 2030. These targets aim to achieve a more competitive, secure and sustainable energy system and to meet its long-term 2050 greenhouse gas reductions target. First, the targets for 2030 include a decrease in GHG emissions of at least 40 % compared to 1990 levels. Second, energy efficiency is aimed to be improved by at least 27 %

compared to "business-as-usual"-projections. Third, a target of at least a 27 % share of renewable energies of total energy consumed is set.

Table 2-1 EU energy targets for 2030 and 2050

	2030	2050
GHG emissions compared to 1990 levels	> 40%	80-95%
Energy efficiency compared to "business-as-usual"-projections	> 27%	--
Share of renewable energy of total energy consumed	> 27%	--

These targets set at EU level do not prevent Member States from pursuing their own, more ambitious targets. The legislative implementation of the targets is currently ongoing, based on a proposal made by the European Commission ("The Clean Energy for All Europeans" package, see below).

The beginning of European energy policy: from the European Coal and Steel Community (ECSC) to the Lisbon Treaty

The EU acts according to the principle of subsidiarity. This principle is fundamental to the functioning of the EU and particularly important in the areas of shared competences between the EU as a whole and its Member States. The principle of subsidiarity aims at determining if the EU or the Member States shall take action. The principle states that the EU may only take action in policy fields if it is able to act more effectively than the Member States at their national levels.

Over the past decades the role of the EU and its institutions in energy politics has changed significantly. Energy issues were at the very core of the first steps of European integration. The European Coal and Steel Community (ECSC) and the European Atomic Energy Community (EURATOM) were key institutions established in the Rome Treaty signed in 1957. The Rome Treaty is generally seen as the starting point of the predecessor institutions of the European Union that was established in 1992 with the Maastricht Treaty. Before 2009, however, when the Lisbon Treaty came into force, energy policies were not unified between the Member States and the EU had no competence in this field. Instead, the focus was on economic or competition policies rather than on energy policies. It was the Lisbon Treaty which defined the policy field of energy as one of "shared competence between the Union and the Member States". This means that both, the Union and the Member States, are able to legislate and adopt legally binding acts in the area of energy. The Member States shall only act if the EU has not yet exercised its competence or explicitly does not want to.

Article 194 in the Treaty of Lisbon on the Functioning of the European Union states that energy policy "shall aim, in a spirit of solidarity between Member States, to

- ensure the functioning of the energy market,

- ensure the security of energy supply in the Union,
- promote energy efficiency and energy saving and the development of new and renewable forms of energy, and
- promote the interconnection of energy networks."

The Treaty of Lisbon, however, explicitly states that the Member States reserve the right to determine their energy mix and the use of their energy resources. The EU is thus not allowed to set national goals for the share of renewable energies.

Current developments in European Energy Policy: The "Framework Strategy for a Resilient Energy Union" and the "Clean Energy for All Europeans"-package

Following up on the 2030 Energy Strategy, the European Commission in February 2015 launched the EU's "Framework Strategy for a Resilient Energy Union with a Forward-Looking Climate Change Policy". The Energy Union strategy focuses on the following five dimensions:

- **Security, solidarity and trust:** The EU aims at diversifying Europe's sources of energy and ensuring energy security through solidarity and cooperation between Member States.
- **A fully-integrated internal energy market:** By supporting adequate infrastructure and reducing technical or regulatory barriers a free flow of energy throughout the EU is pursued.
- **Energy efficiency:** In order to reduce the EU's dependence on energy imports, reduce GHG emissions and drive economic growth a focus is laid on energy efficiency.
- **Climate action - decarbonising the economy:** The EU sees an ambitious climate policy as integral to creating the Energy Union. Actions include the EU Emissions Trading System (EU ETS), targets for sectors outside the ETS to cut GHG emissions, a roadmap towards low-emission mobility and an energy policy which makes the EU world leader in renewables.
- **Research, innovation and competitiveness:** The EU prioritises research and innovation in low-carbon and clean energy technologies in order to drive the transition of the energy system and improve competitiveness.

As part of the Energy Union EU Member States are required:

- to develop Integrated National Energy and Climate Plans that cover the five dimensions of the Energy Union for the period 2021 to 2030 (and every subsequent ten-year period) based on a common template. Hence, the concrete implementation of the common EU policies very much remains in the hands of the Member States;

- to report on the progress they make in implementing the Integrated National Energy and Climate Plans, mostly on a biennial basis.

The importance of national and regional cooperation in the development and implementation of these plans is stressed. At the same time, the fact that different Member States can contribute to the Energy Union in different ways is taken into account. The European Commission monitors the progress of the EU as a whole and subsequently publishes an annual State of the Energy Union report.

In November 2016, the European Commission published a number of legislative proposals summed up as "The Clean Energy for All Europeans"-package. The so-called "Winter Package" aims at specifying the strategic implementation of the EU energy targets 2030 and at advancing the Energy Union. On more than a thousand pages it primarily covers the topics:

- Energy efficiency,
- Renewable energies,
- Design of the electricity market,
- Energy security,
- Governance of the Energy Union.

The package is currently being consulted by the European Parliament and the Council, i.e. by the respective national ministers, following the so-called ordinary, standard legislative procedure of the EU. The common goal is to pass the package by the end of 2018, which would be before the election of a new European Parliament in spring 2019.

Achievement and challenges: Measuring the progress in the EU and a look ahead

The EU pursues three interlinked targets with its energy policies: reducing greenhouse gas emissions, reducing the EU's dependency on energy imports and at the same time ensuring growth and employment.

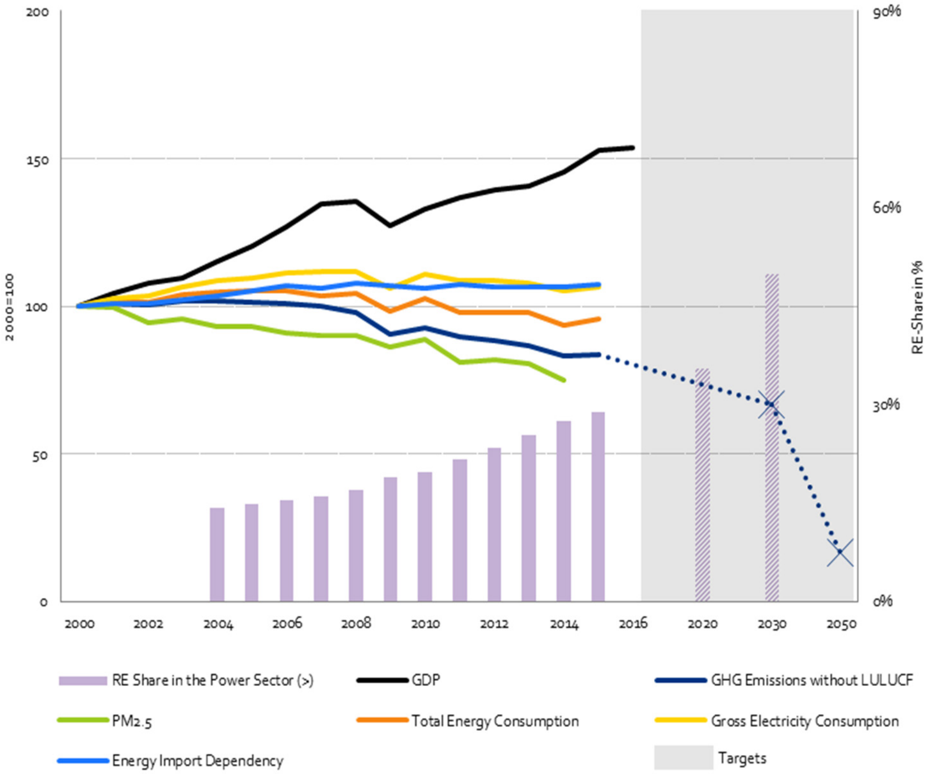
The chart on the key performance indicators for these goals (see below) shows that progress has been made since 2000 concerning each of these targets. The share of renewable energies in the power sector has been more than doubled from 14% in 2004 to 29% in 2015. The GHG emissions in 2016 have been reduced by 16% compared to 2000. Most of the reduction was reached in the years following the year 2009, i.e. in less than a decade which highlights that short and medium term progress is possible. However, considering the ambitious targets set for 2030 and 2050, efforts have to be increased. This does not only imply additional support for technological development for more energy efficiency, but also a thorough check of all emission relevant policy fields, i.e. transport and mobility. That includes the EU level as well as progress on Member State level.

Another indicator for air quality, the PM 2.5, shows slightly more progress, decreasing between 2000 and 2015 by 25%. To determine the value of the PM 2.5 indicator the concentration of fine particles with a diameter of 2.5 µm or less in the air is measured.

Regarding energy import dependency, the chart depicts an increase in the years 2000 to 2006. In the following years until 2015 energy import dependency remains at the same level around 52-54%. Even though the target to decrease energy import dependency has not yet been met at EU level, there are no signs that the increase is a consequence of the energy system transition. For the time being, a correlation between the political decision of pursuing a European energy system transition and the observed increase in energy import dependency at EU level can neither be confirmed nor dismissed.

At the same time the reduction of greenhouse gases on the one hand and economic growth on the other hand are decoupled. Despite the challenges of the global financial crisis in 2008 that strongly hit most Member States, the GDP increased by 54% from 2000 to 2016. Apparently, increased efforts to create a sustainable energy system do not necessarily have a negative impact on the economic development but may instead even improve a country's economic performance.

Figure2-2 Key performance indicators for the energy system transition in the EU[10]



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[10] Targets for the RE Share in the Power Sector are based on PRIMES projections.

On the way towards a European Internal Energy Market

The European energy transition is a challenge that requires common targets and a general framework at EU level as well as close collaboration of Member States. Thus, defining the field of energy policies as one of shared competence between the EU and its Member States was crucial.

Member States have proven to be able to effectively implement a number of concrete steps towards a more secure, economic and ecologic energy system. The EU commission has played a crucial role both by setting ambitious targets many Member States alone would probably not have set for themselves and by working towards a common framework in order to allow for market efficiency and scale effects.

Since one of the founding principles of the EU is the idea of economic cooperation between Member States, the EU is working in the field of energy policy towards a European Internal Energy Market. The idea is for energy to flow freely across the EU – without technical or regulatory barriers. This intends to allow for more competition, to pool the different capacities of all Member States and to improve energy security and system stability. In order to achieve this goal, a fundamental transformation of Europe's energy system is necessary, both with respect to the regulatory framework and to the technical preconditions.

The creation of European organisations like the European Network of Transmission System Operators for Electricity (ENTSO-E) and the Agency for the Cooperation of Energy Regulators (ACER) are two examples of the approach to work towards a European Internal Energy Market. Both organisations aim to connect formerly separate (national) bodies in order to reach a higher degree of market harmonisation.

Transfer to China: A strategic policy approach, good governance and subsidiarity are key elements

The main drivers for the energy transition apply to both the EU and China. With the Paris Agreement almost all states worldwide acknowledged the threat of anthropogenic climate change and committed to actively contribute to "holding the increase in the global average temperature to well below 2 °C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5 °C above pre-industrial levels" by reducing their GHG emissions. Pursuing the energy transition is broadly seen as a vital necessity. However, both the EU and China do not pursue the energy transition for ecological reasons alone but also for strategic political reasons, i.e. due to economic advantages and in order to reduce import dependency.

Even though the EU is not a nation-state but rather characterised as a unique supranational entity, there are structural similarities with large countries like China. In both cases different provinces or Member States play a crucial political role. In terms of energy politics, energy resources and energy supply, there may be significant differences from one region to another. This can be due to geographical or climate conditions or due to historic developments of the structure of energy supply. Consequentially, the governance of such an entity with differing regional interests is highly complex.

The EU's approach to follow the principle of subsidiarity in its effort for an energy transition can be used as example and comparison for the challenges in China. The EU as central entity focuses on setting and monitoring clear common targets and on making sure that the general framework (market structures, regulations, infrastructure etc.) allows for a dynamic development towards a new energy system. The Member States on the other hand have both the right and the duty to implement such policies that contribute to the common targets while at the same time taking into account their respective regional conditions.

Last years development shows that it is possible to advance a secure, economic and ecologic energy system in a cooperative, non-centralised approach between stakeholders with differing particular interests.

2.2 Denmark

From crisis to transformation

The green transition of the Danish energy sector has its root in the oil crisis that hit Western Europe in the early 1970s increasing the oil price significantly and reducing supply of oil to Denmark. At that time most of the energy was coming from imported oil for all major power sectors, power, heat and transportation. The oil price shock sparked a severe economic crisis with high unemployment and booming deficit on Denmark's trade balance. The oil crisis was a wake-up call for the Danish society and political leadership to focus more attention to the planning and diversification of the Danish energy supply including generation of power and heat and focusing on the security of energy supply. At the same time, more political and regulatory attention was put on energy demand including focusing on improving energy efficiency and energy standards.

Over the past 40 years there have been many and comprehensive political and regulatory initiatives to reduce the energy consumption and to convert the energy supply from oil and later from coal and natural gas to renewable energy, especially wind and biomass. The latter was also due to a broader agenda since the 1990s, not only focusing on security of energy supply but also environmental issues including climate change. The focus on renewable energy came despite the exploration of oil and natural gas resources that began in the 1980s in the North Sea. This currently means that Denmark is the only EU member country that is net exporter of oil and natural gas. Also a clear public opposition toward nuclear energy meant that Denmark decided not to develop this energy source, contrary to Denmark's two largest neighbours Germany and Sweden. Despite utilising domestic fossil fuel and renewable energy sources, Denmark currently is a net importer of energy. After reaching a surplus of 35% in 2000, in 2015 13% of gross inland energy consumption where imported. The main reason for this is that the oil and gas production is declining and is now getting closer to the domestic consumption compared to only a few years ago. By then, production was almost twice as much as the Danish consumption. The energy import dependency is, however, still rather modest – particularly compared to other EU countries.

Several long-term plans and strategies have been setting ambitious goals for the development in the energy sector in Denmark. There has been broad political consensus about both the goals and the implementation of the most important initiatives. The involvement and stimulation of the private sector and academia has also been very important for the changes in the Danish energy sector, both in terms of developing new technologies in renewable energy and energy efficiency and in the transformation of energy systems and planning. The private sector has provided important stepping-stones for policy makers to reach and even surpass energy targets and ambitions. Denmark started this journey without having all the solutions.

As a small open economy with a significant part of income coming from trade of agricultural and industrial products and services, Denmark has focused on international cooperation and alliances. As an EU member and active player in international organisations like the United Nations, international treaties and agreements influenced Danish energy legislation, regulation and planning especially after the climate and energy agreements from 2009 and onward. Decisions made at EU-level play an important role and guide a lot of decisions for the energy sector. Denmark has actively been pushing for ambitious EU targets both in terms of new energy sources, open and transparent energy markets and energy efficiency and standards. Both the public and private sector have been able to mobilise funding for the development of new energy solutions. However, as an open economy in international competition all solutions have to pass the test of offering economically viable energy services to companies and consumers. The focus has been on maturing and reducing costs of new energy technologies and systems to serve the Danish society with both economically and environmentally sustainable products and solutions.

Holistic long-term energy planning

In terms of Danish energy policies and framework, in the last decades engaging key stakeholders in the Danish energy supply has been an important factor to ensure broad support for agreements and long-term plans and targets. This helped to secure the business case for the sector moving toward new solutions and business models. The last three energy agreements from 2004, 2008 and 2012 have had broad political support by almost all political parties in the Danish parliament and offered a planning period including targets for more than five years ahead. For a sector characterised by major long-term investments like power plants, grid, etc., it was important to provide visibility on long-term policies and thus business certainty which reduces risk premiums and funding costs. For new and immature energy technologies, Denmark has been offering economic frameworks like feed-in premiums securing the financial viability of the projects. These support mechanisms have been closely monitored to make sure energy consumers would benefit from improvements of the economic efficiency of emerging technologies.

An ongoing dialog between politicians, lawmakers, regulators and key stakeholders in the energy sector including major utilities, technology companies and energy system operators has been key in the development of energy policies and regulation in Denmark. The dialog has ensured good and effective decisions and solutions as well as a high level of investor certainty..

The transition of the Danish energy system has also included smaller consumers and private households. This was done by using a combination of energy standards, incentives and public campaigns focusing on energy efficiency, common energy solutions like district heating and change in everyday behaviour to secure a more energy efficient society. 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 in the allowed energy consumption for heating in new constructions between 1961 and 2010[11]. 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.

Meeting ambitious EU targets for Denmark

As a member of the EU since 1973, Denmark actively follows EU targets for the transformation of the energy sector. Denmark has implemented the market and sector transformation of the energy sector, including international energy trading and unbundling of the power sector. Denmark's "early mover advantage" in combination with its higher than EU-average GDP meant that the country specific targets in the EU's energy strategy 2020 approved in 2009 were significantly higher than the EU average despite the lack of traditional renewable energy options like hydro power. Denmark's 2020 target includes a 31% GHG reduction compared to 1990 level[12] and getting 30% of Denmark's final energy consumption from renewable energy source – both well above the overall EU targets for 2020 that aim at a 20% GHG reduction compared to 1990 level and a 20% share of renewable energies. Projections made by the Danish Energy Agency show that Denmark will most likely surpass both targets with a current GHG reduction of 32% and renewable energy generation share already at 30% for 2015.

Not surprisingly Denmark is set to have more ambitious target for the new country-specific EU 2030 targets. For the non-ETS sector the current proposal from the EU Commission for Denmark is a 39% reduction compared to 2005. This translates into a 48% GHG reduction compared to its 1990 emissions for Denmark by 2030 in relationship to an overall EU target of at least 40% for 2030. As for the EU renewable energy target of 27% by 2030, Denmark aims to significantly exceed this target. The Danish government has set a target of minimum 50% of the Danish final energy consumption to be covered by renewable energy sources by 2030.

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[11] According to statistic from the Danish Building Research Institute

[12] Official Danish GHG targets are compared to 2005 level. In order to increase the coherence of this report data were converted to 1990 level based upon data available for 1990 and 2005. The same method was also used to draft Figure .

As for the long-term EU climate obligation of reducing carbon emission by 85-90% by 2050 Denmark have set a specific national target. Denmark should be able to as a minimum of matching the total Danish gross energy consumption by domestic renewable energy generation by 2050. This not necessary eliminate all fossil fuels in the Danish energy consumption by 2050 but make Denmark as a minimum carbon neutral energy wise. This target will address both the issue of combating climate change and improve security of energy supply.

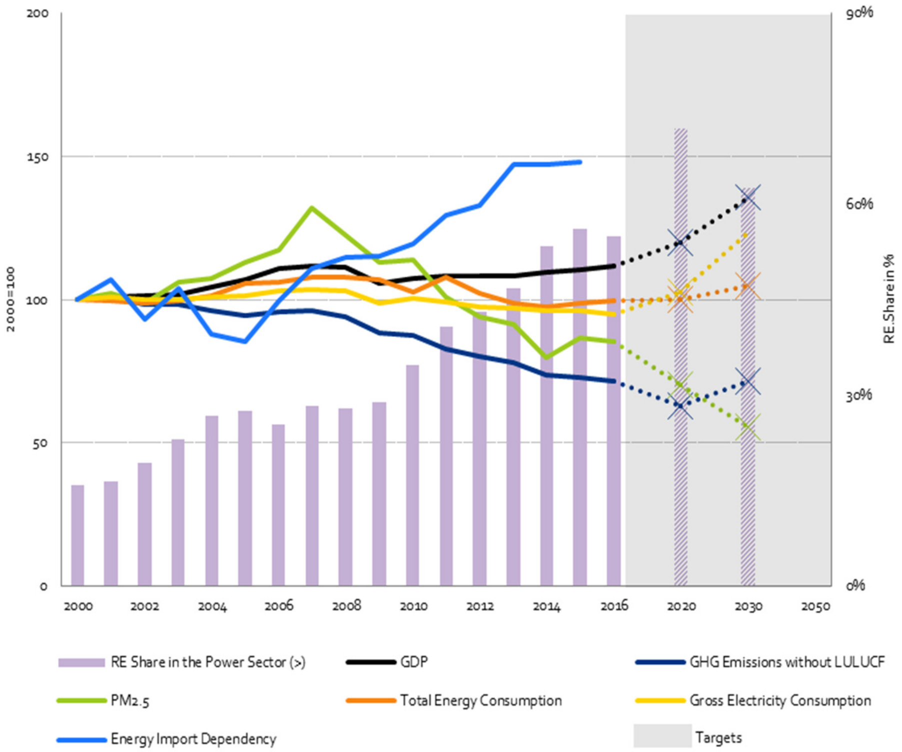
New energy agreement in the making

Based upon the EU energy targets for 2030, the political negotiations on a new energy agreement that will set the course and targets for the period 2020 to 2030 for the Danish energy sector have begun. High on the agenda will be a further transformation away from fossil fuel based energy sources, a further improvement of energy efficiency and creating a market based energy sector securing a cost effective transformation and thus competitive energy prices for consumers and enterprises. For the support of renewable energy sources both EU regulation and recommendations by Danish experts point at more competition based support schemes like the tender system used for the development of offshore wind. This system has enabled the feed-in tariffs (Contract for Difference) to come down by more than 60% between the first major tender auction in 2010 and the latest in 2016.

Decoupling economic growth and energy consumption and GHG emissions

The overall trends of the Danish economy and the energy sector show that Denmark has been able to grow its economy and at the same time reduce the absolute energy consumption and GHG emissions. Since 2000, the GDP in fixed prices has gone up by 11% for 2016. In the same period the Danish total energy consumption has remained at the same level while the adjusted GHG emission decreased by 29%. Analysis shows that the impact of manufacturing industries moving out of Denmark have only had a marginal impact on both energy consumption and GHG emissions. Energy efficiency including combined heat and power generation (CHP) and expansion of district heating and a sharp increase in the use of renewable energies are the most important factors in decoupling economic growth from energy consumption and GHG emissions.

Figure 2-3 Key performance indicators for the energy system transition in Denmark[13]



The most dramatic changes in the Danish energy sector have been going on in renewable energy generation which provided for 30% of the gross energy consumption in 2015. In the early 1990s, renewable energy sources accounted for less than 5% of the Danish power generation. In 2015 that number was 56% due to a significant exploration of Denmark's wind power potential both onshore and offshore (42 and a fuel transformation from coal and natural gas toward biomass(11%). In terms of total thermal power generation, the share of combined CHP has gone up from less than 18% in the 1980s to 80% in 2015. For a normal thermal power plant that means that the energy conversion rate goes up from the around 40% to typically more than 90%.

Denmark has also been able to make the transformation of the energy sector while keeping prices competitive. This applies when energy prices are compared before taxation. As a part of the Nordic power market, the wholesale power prices in Denmark are among the lowest in Europe, even after adding the surcharges of the current support schemes for renewable energy generation and transmission. The improvement of the economic efficiency of new renewable energy capacity including wind energy is part of the explanation. Sharply improved economic efficiency in solar and offshore wind has enabled

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[13] GHG emission targets based upon the preliminary Danish non-ETS reduction target compared to 2005 level. Data do not illustrate official Danish targets.

Denmark to lower feed-in premiums to new projects over the years. The way the Nordic power market functions is another explanation. Due to the combination of very low marginal costs of both wind and hydro power and a day-ahead bidding market that favours the low marginal cost technologies compared to the fuel based power generation sources, market prices are reduced by the so-called merit order effect. Studies show that the wind power in Denmark reduces wholesale prices in Denmark by more than 5%[14].

The flexibility in the energy taxation in Denmark also meant that specific energy intensive sectors with significant export portions have been prioritised to ensure their competitiveness with respect to their international peers. Specific energy efficiency standards and support/incentives to a transformation toward lower energy intensity have further paved the way for lower dependency on energy prices and increased the companies' international competition.

RE integration the Danish way - flexibility and open energy markets

A significant element of the Danish energy transition has not only been introducing new technologies in energy sources, energy generation and energy transformation but also transforming systems and markets to accommodate these technologies both from a technical and economic point of view. A good example of the energy system transformation is how the power sector has been redesigned to accommodate large quantities of fluctuating renewable power generation, particularly wind power. Overall, the Danish power system has gone from a traditional system of a small number of large centralised coal and natural gas power plants to a large number of small de-centralised CHP plants and a large fleet of small-scale wind parks combined with small number of large-scale offshore wind parks as well as lately a number of distributed solar PV installations (mainly integrated into buildings). With almost 50% of all Danish power generation being fluctuating (wind and solar), a number of initiatives and system solutions have been implemented by the Danish transmission system operator Energinet. The main elements have been:

- **Planning and forecasting:** The Danish TSO has developed an advanced system for forecasting expected production from power sources like wind and solar in order to improve planning of generation up until the hour of production and thereby reducing the need for standby capacity.
- **Power plant flexibility and back-up capacity:** Back-up capacity combined with a technical ability of most conventional power plants to adjust generation to significantly less than 50% of their rated capacity means that renewable energy becomes a base load power source in the Danish system.
- **Effective and transparent power markets (NordPool):**The integration of wind and solar has been supported by the Nordic day-ahead power market. Very low

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[14] Morthorst, P. E. (2007): Impact of wind power on power spot prices

marginal cost for wind and solar power means that they are "dispatched" by the market ahead of conventional power sources in the "merit order".

- **Strong domestic transmission grid and cross-border interconnectors:**For balancing and market purposes, strong power interconnectors to Denmark's neighboring countries both in the North (Norway and Sweden) and in the South (Germany and soon Netherlands) enable Denmark to balance under- or surplus production with its neighbors. Especially the hydro-based power generation in Norway and Sweden is ideal to balance fluctuations in wind and solar. This happens through coupled electricity markets, nowadays stretching from Finland to Southern Europe.
- **TSO buying flexibility in the renewable energy sector:**Large wind power projects have shown to be very effective as balancing capacity in windy conditions. A wind park has a very short response time and very low start-up costs. With the help of proper incentives and "virtual power plant control systems", large wind projects can participate in the specific balancing power market getting attractive power prices when the general power market prices are low.

Some of these features and procedures have been developed by the TSO itself, but a lot of the changes, especially in developing the technical possibilities to run existing thermal power plants much more flexibly, have also been made in cooperation with the power sector and large utilities. The transformation from thermal capacity as the base load towards a reactive and balancing load has had significant impact both in technical terms and economically. For the economics of Danish thermal power plants, the transition was partly facilitated by a one-off compensation in connection with the unbundling of the Danish power sector and liberalization of the Danish and Nordic power market. Due to substantial changes in the business model for the main players in the Danish power sector, a deal was made to offset the financial consequences for power assets through a one-off compensation made by government and public budget. The other part of the transition for conventional power capacity is linked to the change of market rules that have created economic incentives to make conventional thermal power units more flexible. Balance responsibility rules had a particularly large impact here.

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 neighboring 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. The Danish energy planning is closely aligned with the EU plans for a more deeply integrated the Energy Union[15].

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[15] See also part A chapter 2.1 on the energy system transformation in the European Union

Denmark did certainly not have all the answers to the questions that were raised when the energy transition began. Energy-related research, development and demonstration programmes providing public support for new products and solutions assisting the green transition have been in place in Denmark for more than a decade. They helped facilitating solutions, systems and markets that were not envisioned before the transition process started.

Transfer to China: Large-scale RE integration and market transformation

China has already introduced a lot of the technologies Denmark has been using for the transformation of the energy sector. Denmark and China are consequently sharing a lot of challenges in terms of system integration and business models for the power sector. Focusing on power plant flexibility in the large coal-fired power plant fleet in China could be a way to address the curtailment issues for fluctuating power sources like wind and solar both from a technical and financial point of view. Conversion of coal-fired power plants into waste or biomass is another way to maintain thermal power generation in a cleaner and more sustainable way. It could lead to reducing the carbon footprint and making use of China's biomass potential. Finally, methods and experiences made in Denmark in terms of power sector planning and scenario analysis could be used to facilitate alternative routes for the energy future of China.

2.3 Germany

The "Energiewende" – energy transition Made in Germany

The German energy transition (so-called *Energiewende*) is a long-term energy and climate strategy towards a low-carbon energy system based on developing renewable energy and improving energy efficiency. It is considered an ambitious industrial and requires technical and societal transformation within Germany and within the whole of Europe. It was launched in the 1990s and its targets are reaching as far as 2050. While its origin lies in controversial debates around nuclear power in the 1980s, it has gained broad political and societal consensus since the 2011 nuclear accident in Fukushima, Japan. The energy transition is based on four main objectives: combatting climate change, avoiding nuclear risks, improving energy security, and guaranteeing economic competitiveness and growth. The Energiewende is an integrated policy framework, covering all sectors of energy and economy. It includes targets and policy measures for CO_2 emissions reduction, renewable energy development, phasing out nuclear energy, and improvement of energy efficiency (see table 1).[16]

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[16] Compare Agora Energiewende (2015): Understanding the Energiewende

Table 2-2 Key German Energiewende targets[17]

		Status quo	2020	2025	2030	2035	2040	2050
Greenhouse gas emissions	Reduction of GHG emissions in all sectors compared to 1990 levels	-27% (2016)*	-40%		-55%		-70%	-80-95%
Nuclear phase-out	Gradual shut down of all nuclear power plants by 2022	11 units shut down (2015)	Gradual shut down of remaining 8 reactors					
Renewable energies	Share in final energy consumption	14.9% (2015)	18%		30%		45%	min. 60%
	Share in gross electricity consumption	31.7% (2016)*		40-45%		55-60%		min. 80%
Energy efficiency	Reduction of primary energy consumption compared to 2008 levels	-7.6% (2015)*	-20%					-50%
	Reduction of gross electricity consumption compared to 2008 levels	-4% (2015)*	-10%					-25%

In recent decades, Germany has significantly diversified its electricity mix toward renewable energy (which grew from 4 percent in 1990 to above 30 percent in 2016), including a sharp increase in citizen-owned projects between 2000 and 2010. However, the share of renewables in other sectors (transport and heating/cooling) has not increased proportionally. To reach the 2020 targets, additional efforts will be necessary. Regular surveys have consistently shown dedicated support for the Energiewende, with more than 90 percent of German citizens supporting its goals.

Widespread opposition against nuclear power as starting point of the energy system transition

The roots of the Energiewende reach back as far as 1950s, when Germany launched a nuclear energy program, though it faced severe public opposition from the start.[18] Public

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[17] Compare Agora Energiewende (2017): The Energiewende in a nutshell; *preliminary

[18] Mez and Piening (2006): Phasing-out Nuclear Power Generation in Germany.

opposition against potential nuclear sites continued in the 1970s and 1980s, however, the 1986 accident at the Chernobyl nuclear power plant and the effects is had also in Germany amplified the debate as well as the perceived risk of nuclear energy technology within the society. After 1986, no new nuclear power plant has been built.

During the 1990s, the debate around nuclear safety was joined by a debate on climate change. A parliamentary commission unanimously voted in favour of a reduction of GHG emissions by 80 percent by 2050. In the 1990s, a first Climate Change Action Plan was adopted by the government, as well as a first plan to support renewable energy sources. The reunification of Eastern and Western Germany lead to a restructuring of the East German power sector, with six nuclear power plants shut down and several coal power plans modernised. In 1997, Germany signed the Kyoto Protocol, committing to a reduction of GHG emissions by 21 percent by 2012 compared to 1990 levels. During the 2000s, a government coalition of social democrats (SPD) and the green party decided to phase out nuclear energy by 2022 based on an agreement between government and energy utilities. The so-called "nuclear-consensus", in which a lifetime of 32 years for every plant was granted and a remaining amount of power to be generated by nuclear power plants was set. Further, strong policies regarding energy efficiency and renewable energy development were introduced, among them the Renewable Energy Act (EEG). The grand coalition of the Christian Democrats (CDU/CSU) and SPD continued these policies, and introduced a climate and energy policy package in 2007, in which a reduction of GHG emissions by 40 percent by 2020 compared to 1990 levels was set. In 2010, the newly elected conservative-liberal coalition (CDU/CSU and the liberal party FDP) adopted the so-called "Energiekonzept", a long-term energy strategy calling for a renewable-based economy by 2050 with ambitious mid- and long-term targets. It included a lifetime-extension of nuclear power plants until 2036.

In 2011, the nuclear accident at Fukushima Daiichi in Japan led to an immediate reversal of the 2010 nuclear life-time extension and reinstated the previous nuclear phase-out until 2022 as passed in 2002. As part of this, the seven oldest nuclear power plants were immediately shut down. The parliamentary vote on this gained a cross-party support of 85 percent (with the remaining 15 percent voting for a quicker phase-out). Currently, all political parties in the parliament agree that there will be no lifetime extension of nuclear power plants.

Since then, the debate around energy transition policies has shifted from the nuclear phase-out towards the expansion of renewable energy and the reduction of GHG emissions. The focus on the expansion of renewable energy is represented by the EEG, in which first a feed-in-tariff for renewable energies has been granted which was financed via a surcharge on the end-user power price. It has been reformed multiple times between 2010 and 2016, setting new targets for the annual capacity additions for every technology and transforming from a fixed feed-in tariff (FIT) towards a feed-in premium (FIP) scheme combined with an auctioning system. Various efforts have been made on national level regarding energy efficiency, however, this matter has mainly been influenced by European policies. While it is debated from time to time whether European targets should be sufficient, Germany has developed and held onto its own, more ambitious targets.

Next to the power sector the reduction of GHG emissions in the transport and heating/cooling sector have become increasingly important in recent years. With various policies and support mechanisms, energy efficiency for heating/cooling in buildings (roughly 60 percent of total energy consumption in the heating/cooling sector) has been pushed effectively. Governmental support includes subsidised loans for investments in efficiency. Standards for emissions from heating systems have driven modernisations. However, heating/cooling in industrial processes has not yet been advanced in a comparable manner.

The transport sector has improved in energy efficiency and emission standards, however, a higher transport volume led to increasing CO_2 emissions and stagnating energy consumption. Recently, scandals concerning non-CO_2 emissions (NOx et al) and fuel consumption have brought up discussions about the transition of the transport sector.

Some progress made and still some way to go

In 2016, 31.7 percent of the power consumption in Germany has been covered by renewable energies compared to 10.2 percent in 2005. With an export of roughly 10 percent of the electricity generated, renewables made up 29 percent of the power generation mix (10 percent wind onshore, 1.9 percent wind offshore, 3.2 percent hydropower, 7 percent photovoltaics and 7.9 percent biomass). 40.3 percent of the power mix was coal (23.1 percent lignite and 17.2 percent hard coal), 13.1 percent nuclear energy and 12.4 percent gas. In 2005, the power mix was dominated by coal with 46.3 percent and nuclear energy with 26.2 percent. Renewables contributed 10 percent.[19] The nuclear phase-out, which is still in process, has been overcompensated with renewable energies.

Since the necessary expansion of the transmission grids is a lengthy process with a lot of legal, political and regulatory challenges, there are relevant delays which are becoming more and more obvious in the overall system management: grid congestions increased and the further development of RE plants is more and more exposed to the risk of insufficient grid structures. In addition to the expansion of the transmission grid, increased system flexibility is pursued by encouraging new technologies and processes (e.g. demand side management, storage technologies, Power-to-X technologies, digitization of system management processes).

Gross electricity consumption has decreased in the past nine years (excluding 2010, the year after the subprime-crisis in which power consumption jumped back on pre-crisis level).[20] In total, about 100GW renewable energy capacities have been installed, about

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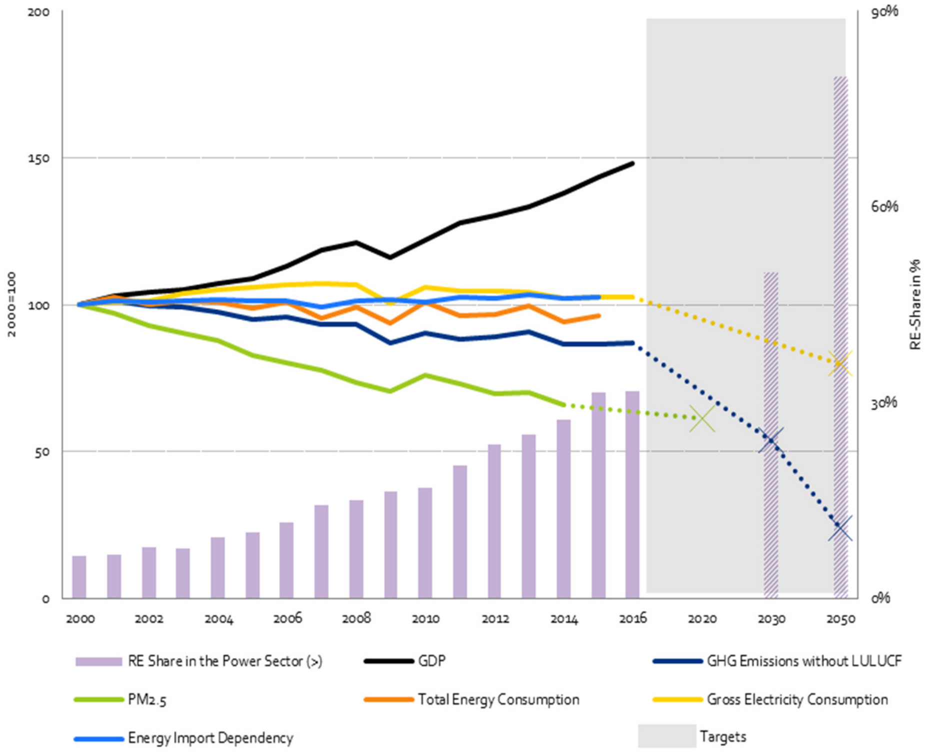
[19] AG Energiebilanzen (2017): Stromerzeugung nach Energieträgern (Strommix) von 1990 bis 2016 (in TWh) Deutschland insgesamt.

[20] Agora Energiewende (2017): Die Energiewende im Stromsektor: Stand der Dinge 2016.

100GW conventional power capacities are installed, of which are 10GW nuclear energy, 20GW lignite, roughly 30GW hard coal and roughly 30GW gas.

Figure2-4 Key performance indicators for the energy system transition in Germany



While the FIT degression scheme has already led to a reduction in prices from above 50 ct/kWh for PV in 2004 to roughly 10 ct/kWh nowadays, auctions for renewables have delivered promising price projections for the future: recent auctions resulted in an average price of 6.58 ct/kWh. The recent auction for onshore wind has resulted in an average price of 5.71 ct/kWh and the recent auction for offshore wind (to be built by the mid 2020s) resulted in prices from 0 to 6 ct/kWh (average weighted price 0.44 ct/kWh). Overall, prices for renewables have decreased tremendously and are expected to decrease further.

In the power sector, CO_2 emissions have decreased in recent years, in 2016 mainly due to a slight switch from coal to gas power generation. However, the vast majority of CO_2 emissions in the power sector come from coal fired power generation.

GHG emissions from the power sector have decreased by 4 percent since 2000 and emissions from the transport sector by 19 percent. However, they have remained more or less on the same level as in 1990 with sharp increases until 1999, decreases until 2009 and then again increases until today. Emissions from the heating/cooling sector decreased by 20 percent.[21]

German electricity costs are amongst the highest in Europe. However, the steep climb has been stopped for the time being. Household prices have increased until 2013 and have remained on a stable level since. Main drivers for this are increasing grid charges and taxes as well as an increasing EEG surcharge. However, the development of the EEG surcharge must be interpreted in combination with the power price component which has decreased since and is part of the surcharge system since 2013. The total of EEG surcharge and power price has increased to 10.55 ct/kWh in 2013 and has decreased since to 9.89 ct/kWh in 2017.[22] Germany has chosen to distribute the burden of the EEG surcharge mainly among households and commercial businesses, while the energy intensive industries are (partially) exempted from surcharge payment to remain internationally competitive. However, the share of household expenditures for electricity has been stable in the past years and is at about 2 percent of total household expenditures. The share of expenditures for energy (electricity, fuel and cost for heating/cooling) is also well below 10 percent in the past decade, peaking in 2013 at 9 percent and decreasing to 7.6 percent in 2015.[23]

Public support for the Energiewende has continued to be very high: ever since 2012, more than 95 percent of the German citizens think that the Energiewende is important or even very important. Deficits, however, are perceived when it comes to the management of it: only about 45 percent of the citizens think that it is well or very well managed.[24]

The paradox of increasing GHG emissions and high cost Lessons Learned

While various smaller and larger lessons learned could be listed here, there are two main challenges to be discussed: Why did emissions increase during a phase in which the share of renewables increased? Why did some costs not decrease as quickly as the prices for renewables did?

Temporarily increasing GHG emissions

Even though Germany has increased its share of renewables since 2000, the CO_2 emissions from the power sector increased in the years 2009-2013 by about ten percent from 301 million tonnes to 331 million tonnes. From 2010 to 2013, power generation from nuclear energy decreased by 43.3TWh (minus 31 percent) while power generation from renewables increased by 47.1TWh (plus 45 percent), the nuclear phase-out was therefore overcompensated by renewables. However, coal power production increased as well by 25.3TWh (plus ten percent), while power production from gas fired power plants decreased by 21.8 terawatt hours (minus 24 percent). Due to higher emissions factors of coal compared to gas, emissions increased accordingly. This effect was due to the lack of an effective CO_2 pricing measure which led to higher marginal cost of gas-fired power plants.

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[21] Agora Energiewende (2017): Energiewende 2030: The Big Picture.

[22] Agora Energiewende (2017): Die Energiewende im Stromsektor: Stand der Dinge 2016.

[23] Statistisches Bundesamt (2016): Private Konsumausgaben und verfügbares Einkommen.

[24] BDEW (2016): BDEW-Energiemonitor.

With increasing power production from renewables, gas-fired power plants were the first to be pushed out of the merit-order.[25]

In the past three years (2013-2016), power production from coal-fired power plants decreased again by 26.7TWh (minus nine percent), while power production from gas-fired power plants increased by 13TWh (plus 19 percent). Further, power production from nuclear energy decreased by 12.7TWh (minus 13 percent) and power production from renewables increased by 37TWh (plus 24 percent). Thus, CO_2 emissions from the power sector decreased by 25 million tonnes to 306 million tonnes.[26]

This was partially driven by fuel prices: during parts of 2016, marginal costs for gas-fired power plants were lower than marginal costs for coal-fired power plants. After various gas-fired power plants were pushed out of the merit-order, now expensive coal-fired power plants are being pushed out as well. To decrease emissions from the power sector more effectively, both inefficient and inflexible coal-fired power plants have to be phased-out by regulation or an effective CO_2 price needs to be put in place in order to increase marginal costs of coal-fired power plants compared to marginal costs of gas-fired power plants.

Cost within the EEG

When looking at prices for renewables and their reduction in the past years, it is not entirely straightforward why the German EEG surcharge has been increasing in the past years and will do so until the mid-2020s according to all prognoses. These increases are due to multiple factors, among them the decreasing power price, which increases the FIP that needs to get paid and of course increasing power production from renewables. The remuneration of renewables has not always been coupled with the true cost of renewable power production. During the years 2008-2013, prices for photovoltaics, and in a smaller scale, wind onshore, have dropped tremendously: wind onshore by about 30 percent and photovoltaics by 40-50 percent. Remuneration remained rather high because FITs were not reduced in the same extent, leading to high capacity additions. Since remuneration is set for 20 years, these costs will prevail in the system until 2030. Germany adapted remuneration starting 2013 and transitioned to an FIP scheme combined with an auctioning system starting 2016. Remunerations are no longer set by the agency but determined via tenders, resulting in less costs for the EEG surcharge. Further, technologies like biomass which have been remunerated quite high during the first years of the energy transition have been limited to low annual capacity additions starting 2014.

EEG cost will therefore remain on an elevated level, leading to further increasing surcharges until 2023.[27] Currently, several alternative financing mechanisms for a better distribution of the EEG cost are being discussed, e.g. introducing a fund with a credit based

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[25] Agora Energiewende (2015): Das deutsche Energiewende-Paradox: Ursachen und Herausforderungen. Updated with new data from AG Energiebilanzen (2017): Stromerzeugung nach Energieträgern (Strommix) von 1990 bis 2016 (in TWh) Deutschland insgesamt.

[26] Agora Energiewende (2017): Die Energiewende im Stromsektor: Stand der Dinge 2016.

[27] Oeko-Institut (2016): Projected EEG Costs up to 2035. A study commissioned by Agora Energiewende.

extension of the payment or a reformed system of surcharges and taxes, possibly including the transport and heating/cooling sectors.[28]

Outlook: Increasing flexibility and digitization of the energy system

The current political debates in the energy sector involve several topics. Among them are discussions about RE capacity additions, especially regarding acceptance among citizens. However, capacity additions, mainly for wind onshore, remain high. In the focus is also the self-consumption of solar power, which is attractive for households and business consumers. In this context, the development and installation of energy storage systems has seen increasing importance as they allow a maximisation of self-consumption and increase system flexibility. An important part of the current debate is also the issue of digitization which is a key element of a successful energy transition. Fluctuating renewables (PV, wind) require a communication network which combines generation, consumers and grids. The energy system needs to always provide flexibility to balance variable RE generation. This is only possible when generation and (flexible) demand can use safe and digital communication channels. The German Government just approved a law on the "Digitization of the Energy Transition".[29] The new government will have to make important decisions reaching as far as 2030 to achieve climate targets regarding coal power production, how transport and heating/cooling sector can contribute to the decarbonisation, and how renewables are able to contribute to this.[30]

Transfer to China: market-based RE integration as cost-efficient way to deal with the complexities of the energy transition

Germany's Energiewende is one example of how a highly industrialised economy can transition its power system towards a climate-friendly, economically competitive system while ensuring energy security. Prices for renewable energies have decreased tremendously in recent years. Experiences with market and system integration measures for variable RE show that a market-based integration with the regulator as a coordinative actor taking into account all relevant stakeholders reduces the costs significantly. Furthermore, long- and medium-term targets have proven helpful to align policies that have short-term effects with long-term goals. Taking into account the lessons learned in Germany, China has the chance to tackle air pollution and create a climate-friendly energy system which equally allows for economic growth.

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[28] Compare Agora Energiewende (2017): Neue Preismodelle für Energie. Grundlagen einer Reform der Entgelte, Steuern, Abgaben und Umlagen auf Strom und fossile Energieträger.

[29] https://www.bmwi.de/Redaktion/DE/Artikel/Energie/digitalisierung-der-energiewende.html

[30] Agora Energiewende (2017): Energiewende 2030: The Big Picture.

2.4 United States of America (USA)

Drivers, Goals and Development

Energy systems[31] in all countries evolve over time as new technologies and business models emerge, and as energy system structure and operations are impacted by diverse mechanisms reflecting a society's values. In the United States, evolution of the energy system has tended to be driven by technology innovation, market competition, and state/local policies expressing citizen preference, rather than by central government planning.

At the present time, considerations of reliability, cost and resilience remain prominent, with lowering carbon emissions from the energy sector a key driver for many consumers, cities, states and businesses. At the national level in the United States there remains uncertainty as President Trump's administration reconsiders a range of extant policies influencing power system evolution. Federal policy has only a partial impact on the ongoing transition, however, due to the division of authority between the states, which have primary jurisdiction over local issues such as customer rates and plant siting, and the federal government, which has jurisdiction over interstate commerce. The impacts of federal policy are often mitigated by the potency of market factors not regulated by the government, such as the price of natural gas relative to the price of coal, and reductions in the cost of new technologies such as wind and solar power.

Below, some key approaches and experiences of the U.S. energy transition are described, with their implications for the future of the U.S. energy sector and thoughts about their relevance for the Chinese energy transition.

Approach and guidelines for the energy system transition

The U.S. energy sector transition experienced over the past decade has been the result of a mixture of market developments and deliberate policies. When Congress signed the Energy Policy Act in 2005, 51.3%[32] of the power sector was supplied by coal, and average vehicle fuel economy was 20.5 miles per gallon (mpg) (11.5 litres per 100 km) passenger cars and light duty trucks[33]. Since then, innovation in fuel extraction techniques such as hydraulic fracturing caused a significant increase in the supply of natural gas, driving natural gas prices lower. This has led to replacements of generation capacity and increased output from existing gas power assets, displacing coal in the power mix. Additionally, renewable energy adoption has increased dramatically, primarily driven by declines in capital costs for wind and solar power systems, and increased investor confidence in the performance of these technologies and state and regional policies.

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[31] For power, transportation and buildings.

[32] https://www.eia.gov/coal/review/pdf/feature05.pdf

[33] https://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/national_transportation_statistics/html/table_04_23.html

The 2005 Energy Policy Act extended tax credits and incentives for production and capital investments in energy efficiency and renewable technologies, and established a standard for blended biofuels in gasoline.[34] Renewable Portfolio Standards (RPS) have been enacted by 29 states and an additional eight have RE goals.[35] The Lawrence Berkeley National Laboratory estimates that RPS policies have contributed to 60% of the cumulative deployment of renewables in the U.S. since 2000.[36] New Corporate Average Fuel Economy (CAFE) Standards were also established during the Obama administration. For example, the CAFE standards for passenger cars and light duty trucks for model years 2017 – 2025 would result in an average 54.5 mpg (4.32 litres per 100 km) fuel economy for these vehicle types. This segment of vehicles represents 60% of transportation-related U.S. petroleum use.[37]

The transition has also been reflected in jobs. In 2017, the power sector made up 39% of all energy sector jobs, while residential and commercial buildings made up 11%, industrial buildings made up 21.4% and transportation made up 28%. Mining and extractive jobs saw a decline of 11.6% over just the last twelve months owing to increases in automation, and employers expect a further 12% decline in the next year. Jobs associated with non-hydro renewable energy accounted for 59% of generation-based jobs, 10% of fuel-based jobs, and 31% of the total. Including hydropower jobs lift these amounts to 67%, 10% and 35%, respectively.[38]

The Obama administration's Clean Power Plan (CPP) targeted power sector emissions - responsible for 29% of 2016 U.S. GHG emissions.[39] It specifically addressed existing power plants fuelled by coal, natural gas, and oil, encouraging investment in new, cleaner generating capacity. The CPP would have reduced power sector emissions by 32% from 2005 levels by 2030, and also allowed states to design customized implementation plans.[40] However, the CPP was effectively frozen by an Executive Order signed by President Trump in February 2017.[41] Energy-related carbon dioxide emissions from the U.S. power sector had already fallen by 25% between 2005 and the end of 2016.[42]

The Obama administration also committed to goals outlined in the U.S. Nationally Determined Contribution (NDC) at the end of 2015 as part of the COP21 negotiations. The NDC set a goal for economy-wide GHG reductions of 26-28% from 2005 levels by 2025, with intent to reach the 28% reduction goal. President Trump has indicated that he does not intend to uphold the U.S. NDC goals. In response, several states and cities have formed

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[34] https://www.c2es.org/federal/congress/109/summary-energy-policy-act-2005

[35] http://www.ncsl.org/research/energy/renewable-portfolio-standards.aspx

[36] https://emp.lbl.gov/projects/renewables-portfolio/

[37] https://www.nhtsa.gov/.../pdf/cafe/CAFE_2017-25_Fact_Sheet.pdf

[38] https://www.energy.gov/sites/prod/files/2017/01/f34/2017%20US%20Energy%20and%20Jobs%20Report_0.pdf

[39] https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks

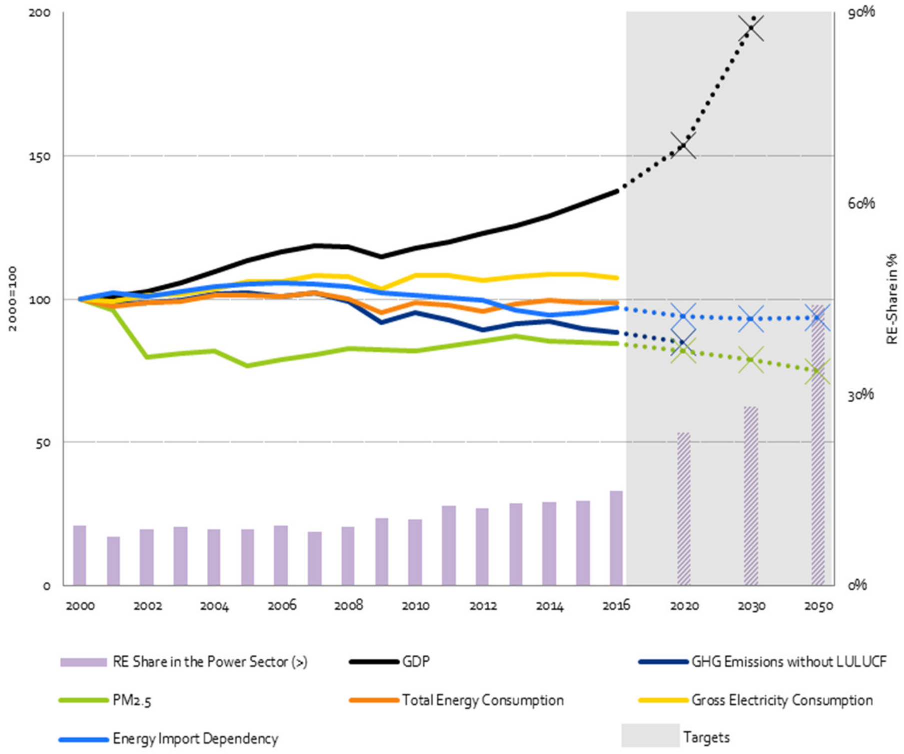
[40] http://www.ucsusa.org/our-work/global-warming/reduce-emissions/what-is-the-clean-power-plan #. WZ3ECmfi_GU

[41] https://www.brookings.edu/blog/fixgov/2017/03/28/the-clean-power-plan-2014-2017/

[42] https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks

a coalition, the U.S. Climate Alliance, to implement the NDC goals at the state level. Additionally, many US corporations who had urged the administration to remain in the pact have since signed commitments to uphold the goals themselves.[43]

Figure 2-5 Key performance indicators for the energy system transition in the U.S.[44]



Experiences and Consequences of Energy System Transition

Some notable points of experience from the U.S. energy sector, and their consequences, are summarized here.

Policy at state and local levels

In the U.S., the primary source of energy policy innovation has been the states, not the federal government. While the current administration has decided not to pursue the CPP; a number of U.S. states already have policies defining a path toward CPP-like objectives.

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[43] http://lowcarbonusa.org/business; https://www.nrdc.org/experts/han-chen/massive-support-paris-agreement-running-tally

[44] The 2020 target value for GHG Emissions without LULUCF is based on the U.S. Nationally Determined Contribution (NDC), which the Trump administration has recently confirmed will not be implemented. The NDC included a 2020 target of 17% below the 2005 value. There was also a 2025 target of 26-28% below the 2005 level, and no targets beyond that date.

Similarly, withdrawing from the Paris Agreement may not affect future U.S. GHG emissions due to these policies. A number of states and large cities have expressed their continued commitment to follow the Paris goals.

The U.S. is a heterogeneous and multijurisdictional policy environment, and thus characterizing a uniform or "typical" policy approach has always been challenging. As one example, a federal RPS has repeatedly failed to be finalized, but many states have implemented an RPS. In Texas and the mid-west, wind development has greatly exceeded the state RPS. The success of regional GHG initiatives, for example in California and the west, and in the northeast, has also reflected geographic and economic diversity that impeded a single national policy.

Market structures and prices

Overall there has been movement in the U.S. from centrally regulated command and control monopoly utilities to competitive markets, but these have taken different forms due to different regional circumstance, political commitments, and transmission interconnections, to name a few factors. An example is the accelerated transition to some form of Regional Transmission Organization (RTO) in the Northeastern, upper Atlantic, Midwestern states, Texas, and (in hybrid form) California. RTOs manage transmission of electric power over geographic areas typically larger than an individual state. Even where there is no movement to a formal RTO, there is interest in greater geographic coordination and in integration under some form of market mechanism. In another example, in some western states not closely tied to California there is growing interest in an energy imbalance market: using a market mechanism to address common problems (hour-to-hour balancing, integration of large penetrations of wind and solar) at lowest cost and least impact on reliability. Even slowly transitioning regions are moving in a similar direction.

GHG emissions impacts

GHG emissions from the U.S. power sector are impacted by a variety of market and policy conditions including fuel substitution between coal and natural gas, renewable energy deployment levels, and energy efficiency, among others. One factor is the great reduction in wind power costs 10-15 years ago, and the current similar trend for solar PV. Another factor is the success of advanced exploration techniques for natural gas (hydraulic fracture, horizontal drilling), which drove down costs dramatically. Since operating costs drive dispatch economics in most jurisdictions in the US, the lower costs of natural gas generation plus the increased penetration of zero marginal cost renewables has created an economic environment where coal and certain older nuclear plants have found it difficult to compete with natural gas, which is now more widely employed, together with wind and solar. This overall landscape has led to reduced GHG emissions from the U.S. power sector. And in transportation, the growing adoption of electric vehicles suggests future net emissions reductions of a magnitude dependent on the power generation mix.

The U.S. demand for power has been relatively stable since 2007, held in check by energy efficiency measures such as LED lighting and improved appliance performance standards that further mitigate GHG emissions.

Economic competitiveness of wind and solar technologies

As the production tax credit (PTC) and investment tax credit (ITC) phase out by 2019 and 2021, respectively, the trend of reduced capital costs for wind and solar is anticipated to continue to the point of near-parity with natural gas and coal generators. There is a near-term dynamic of completing projects while the PTC and ITC are in force, so that for some period after they expire, there may be a slowing of new wind and solar capacity addition, especially in light of the excess natural gas capacity already on line. This dynamic will be affected by the unknown pace of coal and nuclear retirements.

Evolution of the baseload concept

The baseload power concept is becoming less critical, being supplanted by power system flexibility.[45] With sufficiently time-resolved understanding of the demand profile and wind and solar forecasts, operators can assess how much flexibly scheduled power from other sources, including combined cycle natural gas, coal or nuclear, is needed. The impacts on reliability and lifetime of flexible operation of some thermal plants are still being explored and are not yet familiar to operators.

Lessons Learned

In the U.S. the impacts of the energy transition experienced over the past decade were the result of a combination of deliberate, more local (regional, state or community) interventions and bigger shifts in markets outside the control of government at any level.

For the deliberate interventions described above, there has been a very clear impact. Technical standards and policies at different levels of government support a more equitable competitive space for renewable energy technologies. State and local RPS policies accounted for 60% of renewable deployment and drove costs down through cumulative installed capacity. CAFE standards drove innovations such as start-stop engines. Incentives ease the cost and uncertainty burden for early adopters in these transitions. And targeted investments in R&D can address specific concerns of investors and technology limitations.

Market forces also had a significant impact in energy transition and reduction in carbon intensity. Governments now considering adoption of renewable energy face a much easier and less costly decision than those deploying renewable technologies a decade ago, although there are impacts on utility and regulator planning for new infrastructure, such as transmission, market design and operations. The advances in wind, solar and storage are shared globally, resulting in significant leap-frogging potential. The relatively turbulent market adoption pathway felt by early adopters may not be faced by those deploying these technologies today. The pace of this energy transition with respect to market forces in conventional energy sources (i.e., natural gas) was difficult to foresee. Nevertheless, governments at all jurisdictions play a role in ensuring fair, enabling, functional

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[45] See, for example, J. Cochran, M. Miller and O. Zinaman *et al*, "Flexibility in 21st Century Power Systems", 21st Century Power Partnership, https://www.nrel.gov/docs/fy14osti/61721.pdf.

market platforms capable of reliably integrating all forms of energy, thus increasing security, reducing costs and helping to achieve stated social or environmental goals.

Outlook: Current Focus Points and Potential

As renewable technologies improve and become less costly, the focus for energy transition has evolved to be on power system flexibility. This includes the capability of integrating all forms of generation; transmitting power through reliable, physical infrastructure; and managing load, all in a secure and affordable way. The mass deployment of sensors and advanced metering provides significant opportunities with big data never before available. This digitization of the energy sector could create pathways for enhancements from artificial intelligence and machine learning that improve central power system management reducing losses for utilities and costs for consumers.

Conversely, these advances may also have a significant impact on distributed energy systems for those customers who choose to take more control over their own energy production and consumption. Regulators and utilities have an important role to play in maintaining the technical and economic viability of the grid while enabling consumer choice and engagement as adoption of distributed generation and storage continues to grow.

Applicability with respect to China

Beyond the obvious systemic differences, China and the U.S. share a number of common challenges, each country standing to benefit from the experiences of the other. A deliberate approach to sharing lessons learned can have a beneficial long term impact on both countries and on the globe. Some notable aspects are described below.

Momentum of RE development in a dynamic world

Taking a collaborative approach to sharing lessons learned globally can accelerate deployment of low-carbon technologies in all energy markets. This ensures that deployment can accelerate across a broad spectrum of economic development, given many of the original hurdles to deployment were solved by early adopters. Global demand may also provide larger and more consistent (less cyclical) market signals to manufacturers and technology innovators. And technologies especially suited for earlier adoption in some countries may undergo sufficient learning and cost reduction to be more broadly applicable.

Needs for Technology Research and Development

Advances in technology will further enable greater deployment and broader application of renewable and other advanced energy technologies. There is still room to achieve higher efficiencies, lower costs, and better environmental sustainability in manufacturing of these technologies. Such continued advances could accelerate the energy sector transition to a low-carbon composition. Some examples include:

- Solar PV chemistries that are not reliant on rare materials and can be inexpensively mass produced

- Higher wind turbine towers to expand areas of deployment, and flatter power curves capable of higher output at low wind speeds
- Cost reductions for Concentrating Solar Power (CSP) technologies
- More robust cost and performance data for marine hydrokinetic technologies
- Geothermal resource assessment and data availability
- Advanced inverters and power electronics that enable more seamless integration of renewable energy
- A variety of large-scale, inexpensive storage technologies that can match specific power sector needs at any time scale.

Industry Maturation: Standards

One hallmark of mature industries is the existence of standard contracts, codes and standards, which reduce transaction costs and increase regulatory certainty. As the renewable energy industry matures, an increasing share of cost reductions may come from the establishment of these standards. For example, standard parts and connections for solar PV racking systems could streamline installation and lower costs. Similarly, establishing standard contracts improves investor confidence and lowers transaction costs associated with financing. These efforts can have a marked effect on the quality and long term performance of these systems. Establishing these standards globally can accelerate adoption by allowing global players to participate in foreign markets more easily than establishing and reviewing contracts on a country-by-country basis.

Flexible Power Systems

Perhaps the biggest challenge energy sectors face globally is the effective integration of variable renewable energy at high penetrations. This challenge will be much more prevalent and pervasive as the industry grows and countries implement their policy goals. Effective integration can be achieved through effective planning for system flexibility and power market design.

Power system flexibility can be achieved through understanding the flexibility and ramping capability of existing technologies, characterizing the spatiotemporal nature of variable renewable resources, designing physical infrastructure capable of transferring power from source to use, and understanding load profiles and flexibility. Doing this reliably on an ongoing basis can be achieved with commercially available technology and proactive power system and market design.

On the operational and market levels, new approaches are being developed for designs that can effectively and reliably integrate variable renewable energy. These include increasing balancing areas, reducing dispatch time and creating rules for flexible generation. Market-based pricing for energy, capacity and ancillary services can be established to compensate for the benefits provided by each technology. Similarly, coordination approaches between balancing areas and novel tariff design can incentivize participants to consume energy in an optimal way.

The challenges associated with a transition to a low-carbon energy sector are becoming better defined, with solutions for many already identified. While economic, political and social differences exist among all nations, core technical, physical and business-based solutions appear to be consistent and broadly applicable. Institutional coordination among countries to share these innovations and lessons learned can bolster global progress in the energy transition.

3 Drivers for the Chinese energy transition

3.1 Overall strategy for the development of China

The 13th Five Year Plan pointed out the direction and comprehensive strategy for the future development of China. From the time-line perspective, the Four-Pronged Comprehensive Strategy (Finishing building a moderately prosperous society in all respects, deepening reform, advance the law-based governance of China and strengthen Party self-governance) should be persisted, and meanwhile prioritize the development, realize the 1st Centenary Goal and solid the base for the 2nd Centenary Goal. From the social-economic development perspective, the vision of innovative, coordinated, green and inclusive development should always be practiced to promote balanced economic, political, cultural, social and ecological progress.

China has set out a new path for development, on which the ecological progress had already been regarded as the core content. "Ecological prosperity always go with the civilization progress." Since the 18th CPC National Congress, the ecological progress had already gained its important strategic position. Meantime, the vision of green of the New Development Concepts would function in the 13th FYP period and even beyond, which guiding both the production and the consumption. The pleasant ecological environment is the fairest public welfare widely shared by the citizen. The environment issue is one of the most severe problems not only for China but also the whole world today, which gained great concern from the people. Once the ecological environment damaged, both the government budget and the social development suffered, which would tremendously affect the living standards. Thus, President XI Jiping emphasized that "to protect the Eco-system just as to protect our eyes, and to treat the Eco-environment just as what we do to live." The most suitable illustration for the "Green "development concept is as the saying goes "Beautiful scenery is the gold and silver mines".

Balanced Economic, Political, Cultural, Social and Ecological Progress & Energy Development

- To promote balanced economic, political, cultural, social and ecological progress, the Economy development should be the in leading position, and the Ecological progress is the final stand. At the current phase of China, there is an irresistible relationship between the economy and energy development. China's energy portfolio, coal still took huge accountability, and the total energy consumption amount ranked 1st in the world. With this pattern to support the economy, will definitely lead to high level of emissions and pollutions. Therefore, it is an inevitable choice to take ecological progress as the guidance and constraints for the energy transition and sustainable development, which is the new path for both China's economy and energy development. Energy provides service to the**economy**; for the economy to deliver high quality and sustainable products, the energy system at the same time should provide the same standards products for the economy.

- Positive **social** development can only be achieved by moving away from fossil fuels to a clean and efficient energy system to reduce pollution, secure people's livelihoods, and improve quality of life.
- To respectenergy system is the further key in making sure that the natural boundaries for **ecological** development are respected and neither resources nor sinks are overused.
- **Political** development provides the framework for the energy system to develop. Well-designed political reforms will make sure that the right incentives and mechanisms are in place to reach a low-carbon and green energy system.
- The way energy is used is in many ways rooted in **cultural** aspects of society. Changing behaviour in terms of when and how energy is used has a major impact on the energy system.

By 2020, which id the end of the 13th Five-Year-Plan period, China will have established a solid base for a resource-efficient and ecologically sound society. Innovation is the key to the overall development strategy and there should bea specific focus on development of new energy, energy conservations, and pollution reduction.

Main principles of Ecological Progress

Balance

Chinese development has been fast-paced and intense; with double-digit GDP growth rates for many years the Chinese economy has developed rapidly and lifted hundreds of millions of people out of poverty. However, this impressive growth has been achieved at a high environmental cost. Stress on China's environmental carrying capacity is evident with widespread air, water, and soil pollution issues as well as an extensive water shortage. China commits to creating an Ecological Civilisation with a balance between people and nature. A central principal in the Ecological Civilisation is to keep development within natural boundaries and not exceed environmental carrying capacity.

Efficiency

Green, circular and low-carbon development requires efficient use of resources; this is also valid with regards to energy resources. Saving energy is highly prioritized and energy intensity should be strictly controlled. China has reduced its energy intensity 30% over the first 15 years of the century, making it a world leader in energy efficiency improvements[i]. The energy intensity rates will continue to improve; this will be achieved through improved efficiency in industries as well as a shift from an economy reliant on heavy industry to higher value manufacturing and the service industry, realising the economic "new normal".

Transparency

Changes will be implemented through reform focused on innovation and transparency. Rights to natural resources should be transparent and benefit the people. The public should be active and aware and governance structures should be clear and those responsible should be held accountable. Targets should be monitored and evaluated systematically.

The regulatory system sets the framework for setting and respecting redlines to ensure balance.

Industrial development

The economy is undergoing structural changes, adapting to the economic "new normal"[46] and moving from quantity to quality. Restructuring the economy from one centred on heavy industry to the economic new normal with stabilised growth rates and where the service sector is the largest sector of the economy, is an ongoing process promoted by the Chinese government. In 2014, the service sector for the first time took over the industry sector in terms of GDP (see Figure 6). In 2016, the tertiary industry grew 7.8 % year-on-year while the secondary industry grew 6.1 % and the primary industry 3.3 %. The service sector has gradually increased its share of employment and in 2016 it employed 43.5% of Chinese workers[ii].

Another major shift is moving from quantity to quality in manufacturing with the Made-in-China 2025 strategy. Production of low quality products is to be replaced with high quality products to satisfy both national and international demand. This includes greening the industry and one of the focal areas are low-carbon energy technologies and electric vehicles. This new industrial structure requires sets a different range of demands to the energy system. The previous strong link between economic growth and increasing energy consumption is no longer valid, which removes the need for a rapid growth in energy supply.

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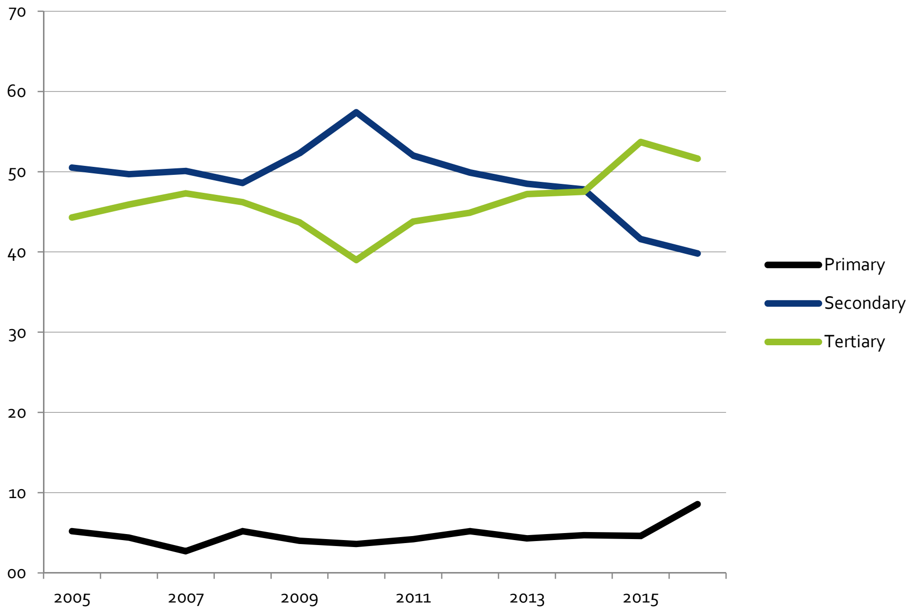
[46] The term "*new normal*" was first mentioned in China during Xi Jinping's visit to Henan in May 2014. Xi Jinping said, "China is still in an important period of strategic opportunity for development. We must boost our confidence, adopt ourselves to a *new normal* based on the periodic characteristics of China's current economic development, whilst strategically maintaining a steady and peaceful state of mind."New normal economy denotes shift of economic paradigm, reformation of economic development mode and transformation of economic growth pattern. New normal economy is a new economic form and development mode that is different from the old, GDP-oriented one. New normal economy denotes promoting development through growth, departing from focusing only on GDP growth to stressing all-round development of the society, replacing the price mechanism with a value mechanism as the core mechanism of the market, and making the goal of the reform and opening up a sustainable socialist market economy, instead of a capitalist market economy under which growth is unsustainable.

Figure 3-1 Share of GDP in main sectors. Source: NBS



The energy system needs to be transformed to supply the necessary services to support this new qualitative growth model. Letting the core principals of Ecological Civilisation guide Chinese development ensures a path to a sustainable society. The energy system fuels this development and is an inherent part of realising this vision.

Implementation

The Ecological Civilisation embodies a set of values to guide how resources are used. Letting these values settle throughout society involves wide and deep reforms. This has for example been exercised in the nation-wide air quality monitoring system and pollution permit systems. Environmental indicators are playing and increasingly important role in national plans. All land areas will be divided into different categories specifying the suitable intensity and type of development for the area. This is part of setting the red lines for development and adhering to the natural boundaries of environmental carrying capacity. Standards for resource and energy consumption, and pollution management systems are part of making sure that resources are used efficiently. A set of targets for implementing the Ecological Civilisation until 2020 include[iii]:

- Establish boundaries for use of ecological services
- Reduce carbon, water, and energy intensity
- Cut air pollutants and improve air quality
- Keep soil quality stable
- Control environmental risks
- Enhance ecosystem stability and control biodiversity loss.

As well as[iv]:

- Establish a nation-wide carbon ETS
- Improve energy conservation standards
- Establish energy consumption targets on national, provincial, enterprise level.

Planning should be integrated and coordinated at all levels and across governmental departments and strengthened by international cooperation.

3.2 International commitments

China has repeatedly made clear its international commitments as a responsible developing economy. In times of international uncertainty China has cemented its commitments and taken an even larger role as a frontrunner in climate change mitigation and adaptation efforts, not least when signing and ratifying the Paris Agreement. The agreement stipulates that the parties keep global warming well below 2 degrees, aiming at 1.5 degrees. Another major international commitment is the Sustainable Development Goals, where UN member states got together and set international targets for 2030 to ensure sustainable development. These include access to affordable, reliable, and modern energy for all, increasing energy efficiency and the share of renewable energy, addressing climate change though mitigation and adaptation. The specific focus on making cities resilient and sustainable is of great importance to China as most people live in cities, 57% in 2016[v], and the urbanisation rate is expected to increase.

In its INDC ahead of the Paris negotiations China committed to reach the following targets by 2030:

- PeakCO2 emissions around 2030 and making best efforts to peak early.
- Reduce CO2 emissions per unit of GDP by 60% to 65% from the 2005 level.
- Increase the share of non-fossil fuels in primary energy consumption to around 20%.
- Increase the forest stock volume by around 4.5 billion cubic meters from the 2005 level.

3.3 New path for the energy system

The Paris Agreement and the Sustainable Development goals are in line with the values of the Ecological Civilisation, as sustainable development is a prerequisite for future generations to enjoy ecological goods and services. It requires a radical change in the way energy systems are designed and managed; only a low-carbon, sustainable, and efficient energy system can support this new development path. The CREO shows how the energy system can support this path and that reaching a "Beautiful China" is possible when development is guided by the Ecological Civilisation values.

4 The current energy system status in China

In 2016, China speeded up the supply-side restructuring of the energy sector. The fuel mix continued to diversify and the share of non-fossil fuel in China's final energy consumption increased. However, problems with supply overcapacity, specifically in coal power, remain prominent and extensive renewables curtailment is slowing down the decarburization of China's energy system.

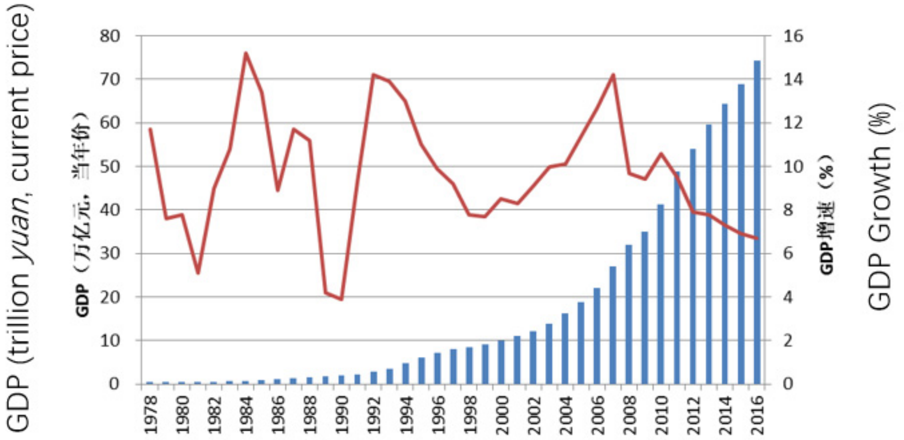
4.1 Energy demand

Energy demand has increased, but the share of coal went down for the third year in a row. China's total energy demand is expected to continue to grow, but at a low rate due to industrial restructuring and advancements in energy efficiency.

Demand goes up while coal consumption decreases

With over three decades of reform and opening up, China has enjoyed continuous and rapid economic growth and significantly-strengthened comprehensive national power. The country's GDP increased from 454.6 billion in 1980 to 74.4 trillion yuan in 2016, growing at an annual average rate of nearly 10%. In 2010, China's per capita GDP exceeded US$4,600[47]. Per the World Bank's 2010 standard, China has already joined the ranks of the world's middle income countries. In 2016, China's per capita GDP reached US$8,000, at the medium level of high- and middle-income countries.

Figure 4-1 National economic growth (1978-2016)



Data source: China Statistical Yearbook over years

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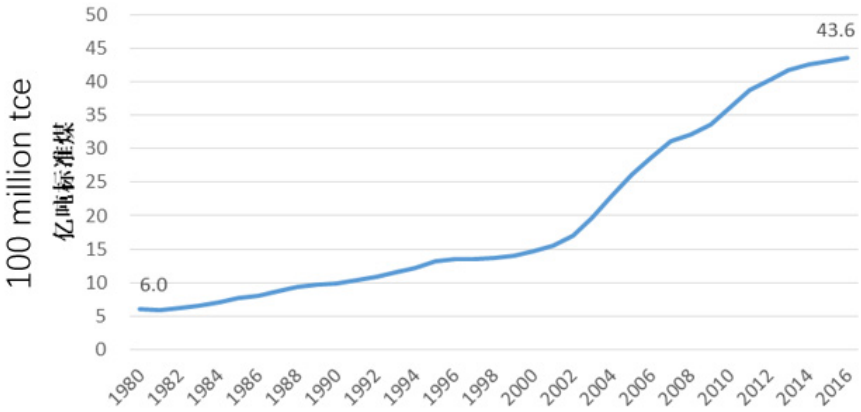
[47] Measured at a USD to CNY exchange rate of 6.7.

Driven by steady and fast development of national economy and society, China has seen over the past three decades its total energy consumption rising rapidly from 600 million tce in 1980 to 4.36 billion tce in 2016, at an average growth rate of 5.7% per year. Generally, there are three stages: the 1st stage began in 1981 and ended in 2000, a period witnessing a constant growth of total energy consumption, which more than doubled within two decades. Total energy consumption increased by 870 million tce, at an average growth rate of 4.6% per year; the 2nd stage began in 2001 and ended in 2010, a period witnessing a high-speed growth of total energy consumption. Within the span of one decade, total energy consumption more than doubled again, with an increase of 2.14 billion tce, or 2.5 times the increment of the previous two decades. The average annual growth rate rose to 9.4%; and the 3rd stage began in 2011 up until now. This marks a period witnessing a low-speed growth of total energy consumption, at an average growth rate of 3.2% per year. Despite sluggish growth, increment in energy consumption remains huge. Total energy consumption rose by approx. 750 million tce within the span of 6 years.

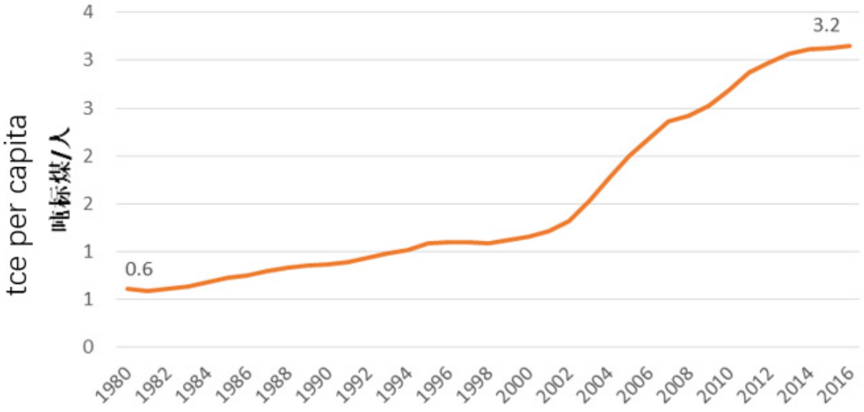
Figure 4-2 Total energy consumption (1980-2016)



Data source: China Statistical Yearbook over years

Average energy consumption per capita increased significantly by 4.3 times from 0.6 tce/person in 1980 to 3.2 tce/person in 2016.

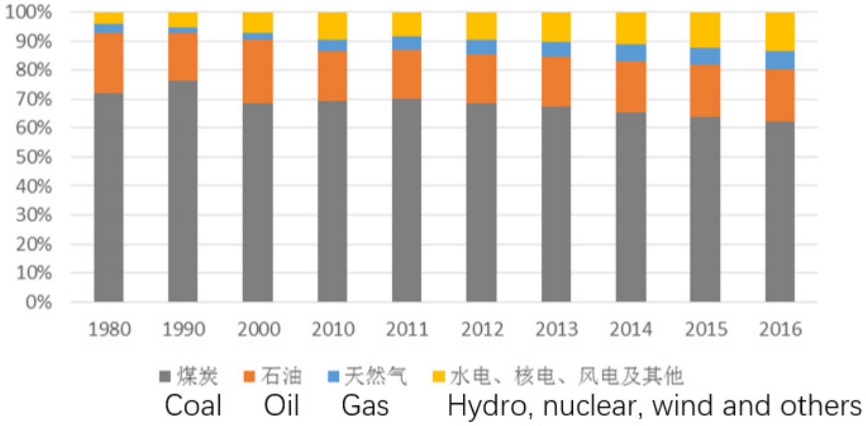
Figure 4-3 Average energy consumption per capita (1980-2016)



Data source: China Statistical Yearbook over years

Coal still remains a dominant component of the energy mix in primary energy consumption, although its share continues to decline. In 2016, coal accounted for approx. 62. 3% of total primary energy consumption, a decrease of 10% compared to its 1980 level. In addition, the share of non-fossil fuels is still low at merely 13.3% in 2016.

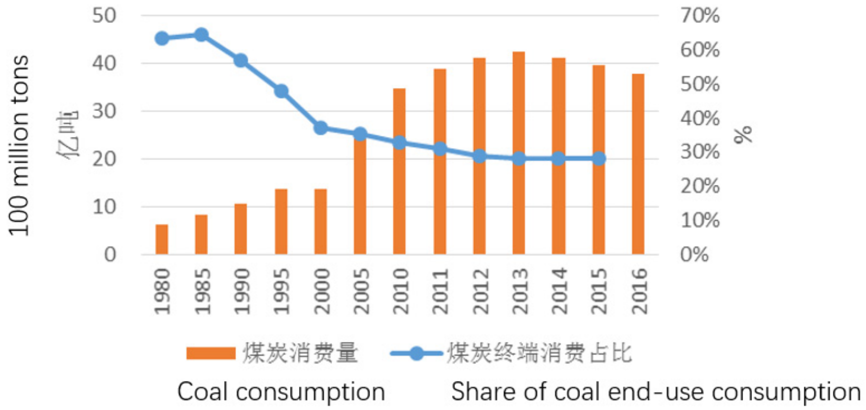
Figure 4-4 Energy mix in primary energy consumption (1980-2016)



Data source: China Statistical Yearbook over years

Coal has long been the No. 1 energy source in China. In 2016, coal consumption decreased by 4.7% to approx. 3.78 billion tons. This marked the third consecutive year of declining coal consumption since 2014. Its share in primary energy consumption, which dropped to around 62.3% in 2016, has also shown a gradual decreasing trend. But from a global perspective, China is still the world's largest country in coal consumption and contributes to around half of the world's total coal consumption. With continuous optimization of the consumption structure, coal as a share of final consumption shows a continuous and significantly decreasing trend. The number dropped to 28% in 2015.

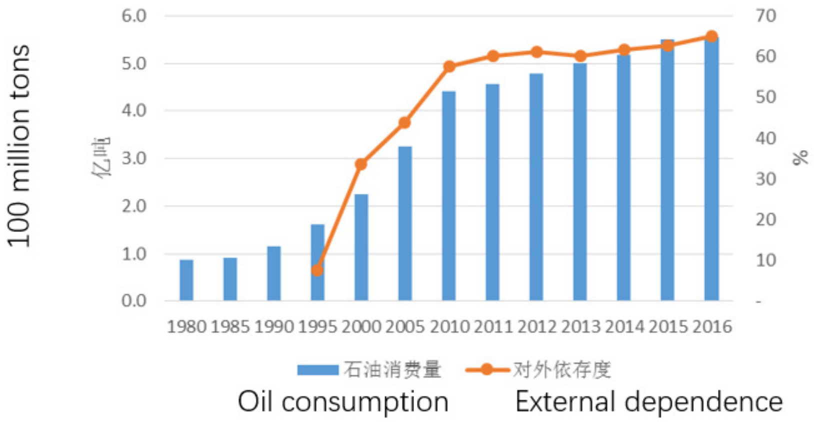
Figure 4-5 Coal consumption and its share in final consumption (1980-2016)



Data source: China Statistical Yearbook over years

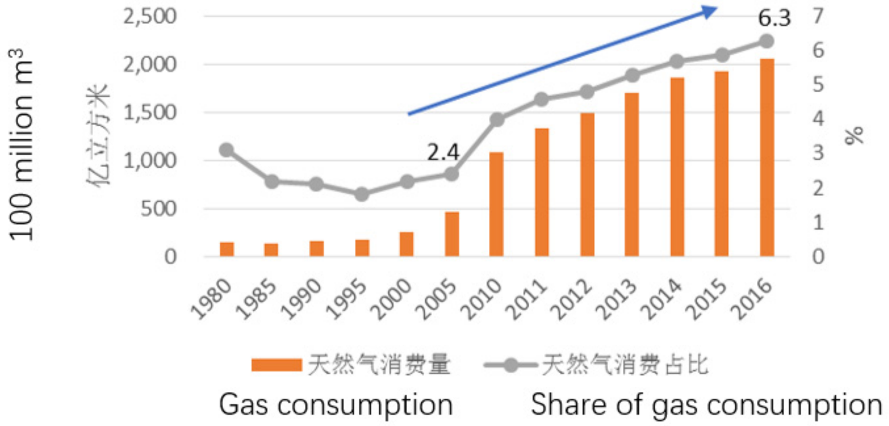
Oil is the second largest energy source in China. Since the late 1990's, oil consumption has witnessed steady and rapid growth due to rapid social and economic development. It more than doubled quickly from less than 100 million tons in 1980 to nearly 560 million tons in 2016.

Figure 4-6 Oil consumption and degree of external dependence



Data source: China Statistical Yearbook over years

Figure 4-7 Natural gas consumption and its share in primary energy structure (1980 – 2016)



Data source: China Statistical Yearbook over years

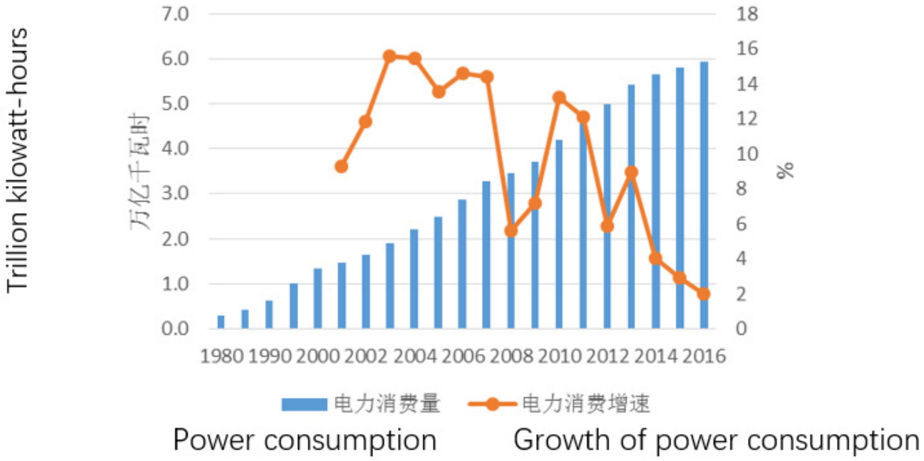
Compared to other fossil fuels, natural gas started late in the market. Prior to 2004, natural gas was used only as a by-product of oil. Its characteristics as a superb energy source were not fully recognized. Absence of necessary infrastructure also caused the natural gas market to grow at a comparatively slow pace. The west-east national gas transmission project, which was completed and put into operation in 2004, marked the start of a rapid development stage for natural gas in China. China's apparent consumption of natural gas quickly rose from 46.6 billion m3 in 2005 to 205.8 billion m3 in 2016, an annual average growth rate of 14.5%. That having been said, natural gas share in China's primary energy structure has always remained low. Over the past 16 years, it only rose by 4%.

Increased power consumption by households and the tertiary industry

With the steady and rapid socio-economic development and increased energy consumption, China's power consumption level rose significantly. During 1981-2016, the country's average annual growth rate of power consumption reached 8.6%; with 5.9 trillion kWh in total power consumption, China surpassed the US in 2011 as the biggest consumer of electricity in the world. Nevertheless, the country's average power consumption per capita, particularly that by household, still remains quite low. Average power consumption per capita stayed at the level of approx. 4,200 kWh in 2016.

To meet people's living needs, the tertiary industry saw rapid development especially in the early days of the reform and opening up. During the 1980s and 1990s of the last century, power consumption grew at an average annual rate of 7. 8%. The elasticity ratios of electricity consumption were 0.81 and 0.79, respectively. With the gradual upgrading of the consumption structure after 2000, automobile and housing have become new consumption hot spots, which gave impetus to the development of energy-intensive industries. As a result, average annual growth in power consumption reached 12.0%, and elasticity ratio of electricity consumption 1.13, during 2001-2011. With the economy entering a new normal after 2012, growth in power consumption has significantly slowed down. During 2012-2016, average annual growth in power consumption dropped to 4.7%.

Figure 4-8 Power consumption and growth rates (1980-2016)

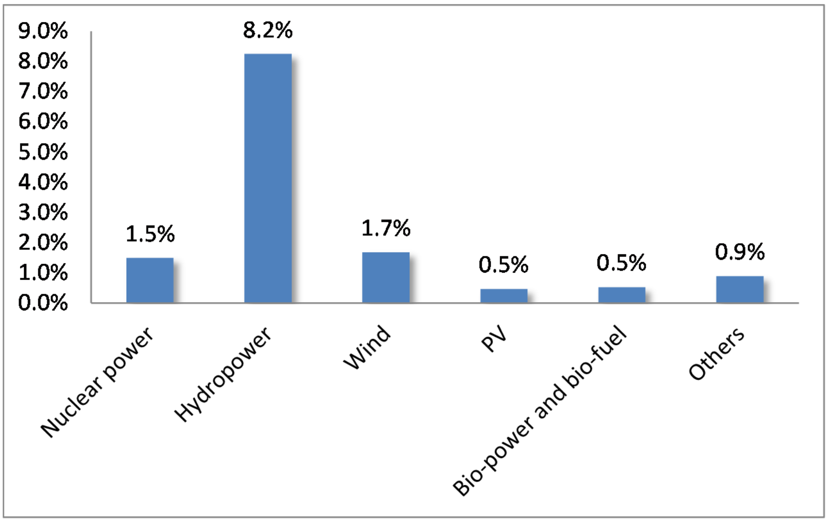


Data source: China Statistical Yearbook over years

Non-fossil energy share is increasing

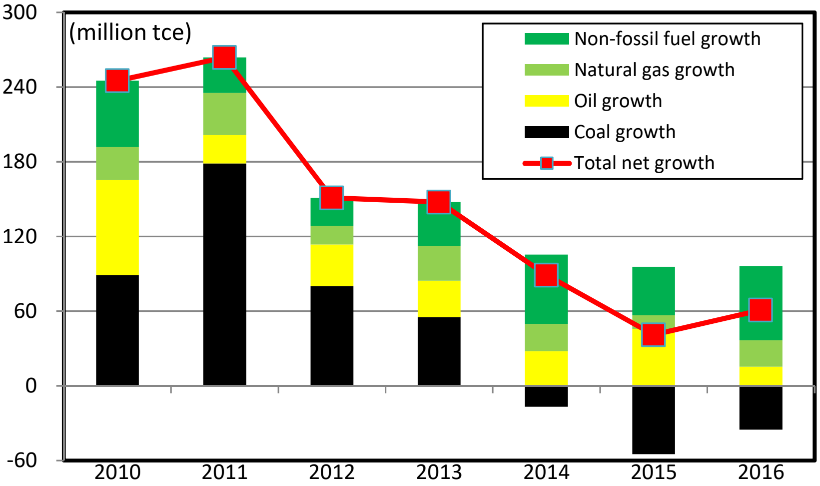
In 2016 total non-fossil energy use reached 541 million tce, accounting for 12. 4% of the country's total primary energy demand. When adding geothermal heat, solar water heaters, and other biomass energy, non-fossil energy sources made up 13.3% of primary energy consumption. This is up 1. 3 percentage points year-on-year and up about 5 percentage points since 2011.

Figure 4-9 Ratio of various non-fossil fuels in the primary energy consumption of China in the year 2016. Source: Calculated by the author with original dataset announced by National Energy Administration.



Non-fossil fuels made up the largest part of overall growth in energy demand in 2016. Coal production fell while non-fossil fuels increased nearly 60Mtce (see Figure).

Figure 4-10 Growth in energy demand by energy resources of China. Source: National Bureau of Statistics



More cars and trains affect oil consumption

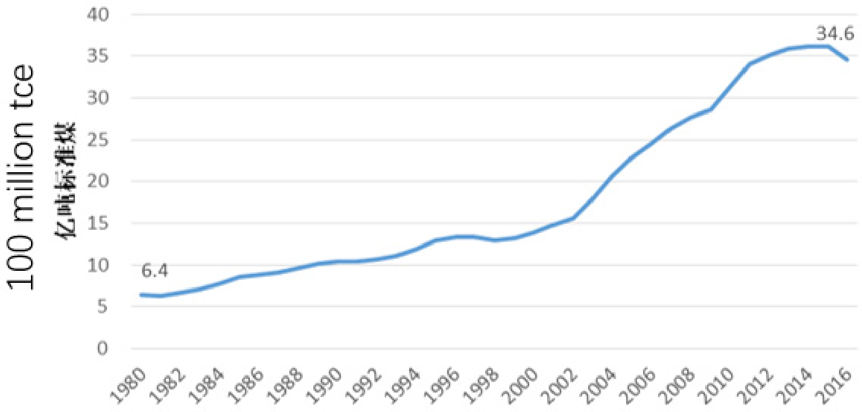
China's total consumption of oil products reached 289 million tons in 2016, an increase of 5% compared to 2015. An increase in the number of cars pushed up gasoline consumption 12. 3% while the proliferation of high-speed trains slowed down growth in jet fuel demand. The growth in jet fuel consumption was 10. 4%; nearly 7 percentage points lower than in the previous year. Driven by oil products consumption and influenced by large crude imports, China's total apparent oil consumption reached 556 million tons, an increase of 5.5% year-on-year. China's crude oil demand is expected to increase slightly, which will be covered by imports as domestic production is expected to decrease.

4.2 Energy supply

Fossil Fuel will still be the main force for energy spply

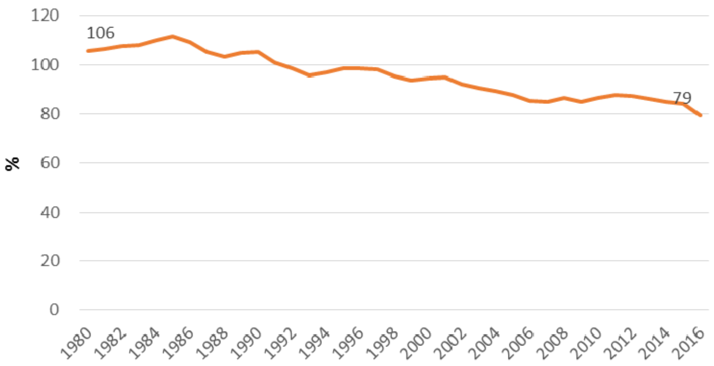
Ever since the reform and opening up, China's energy industry has grown very rapidly, with the country's energy production capacity significantly improved. This provides robust support for steady and fast development of economy and society as a whole. China's total production of primary energy has grown from 640 million tce in 1980 to 3.46 billion tce in 2016, representing an average annual growth of 4.8%; it has maintained a high-speed growth momentum for nearly a decade especially after 2002, with the average annual growth rate climbing to 8.7%. In 2007, for the first time in history, China surpassed the US in energy production as the world's top energy producer. China has always adhered to the policy of relying on herself for domestic energy supply. The country's energy self-sufficiency rate has long remained at a high level of 80-90%.

Figure 4-11 Total production of primary energy (1980-2016)



Data source: China Statistical Yearbook over years

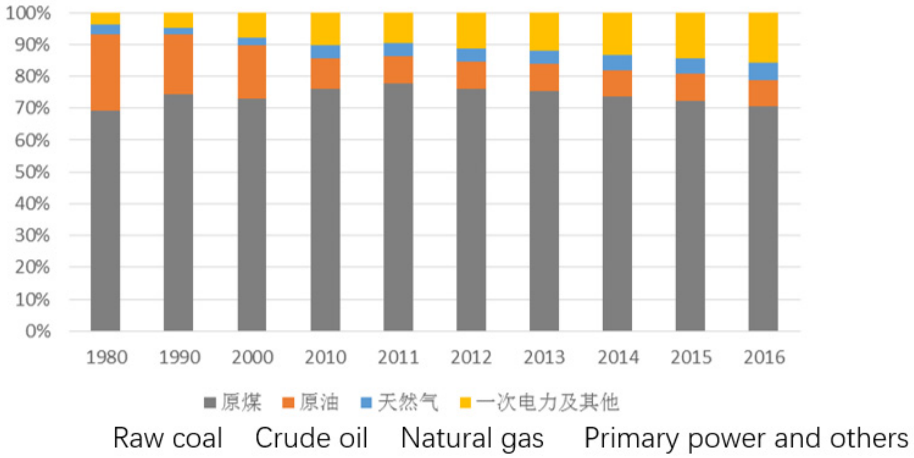
Figure 4-12 Self-sufficiency rate of primary energy (1980-2016)



Data source: China Statistical Yearbook over years

China has already formed a fully-fledged energy production and supply system composed of coal as its foundation, electricity as its center and other energy sources, like oil, natural gas, new energy and renewable energy. Of the country's total primary energy production in 2016, raw coal, crude oil, natural gas and primary power accounted for 70.7%, 8.3%, 5.3% and 15.7%, respectively. Compared to the 2000 levels, shares of raw coal and crude oil declined by 2.3 and 8.5 percentage points, while that of natural gas increased by 2.7 percentage points. Shares of nuclear, hydroelectric and renewable power combined increased by 8 percentage points. Optimization of the country's primary energy production structure was carried out at a comparatively rapid pace.

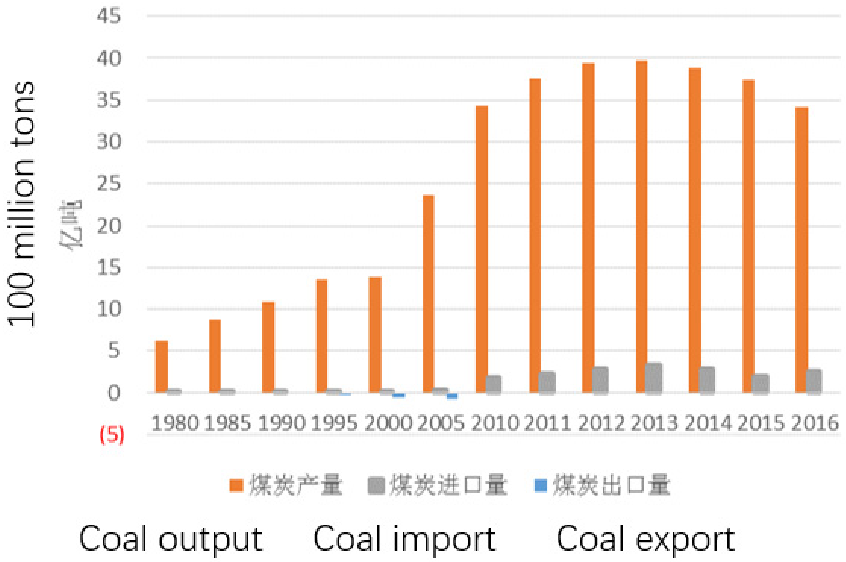
Figure 4-13 Primary energy production structure (1980-2016)



Data source: China Statistical Yearbook over years

Coal production and imports grow steadily. While production increased from 620 million tons in 1980 to its peak of 3. 97 billion tons in 2013, imports grew from 1.99 million tons in 1980 to its peak of 330 million tons in 2013. The coal market has remained weak over the past few years, with coal production declining for three straight years after 2014. Affected by both weak market demands and the deepening of cuts in excess industrial capacity in 2016, coal production dropped significantly by 340 million tons to 3.41 billion tons, a decrease of approx. 9% year over year or a 14.2% decline compared to its 2013 peak.

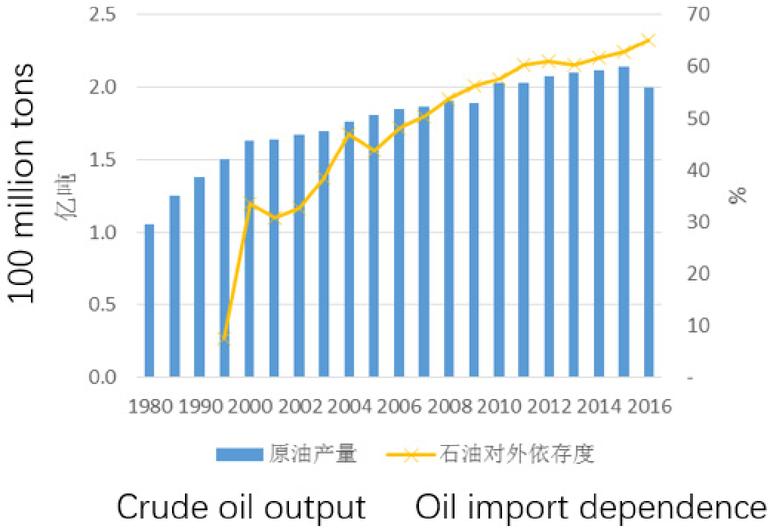
Figure 4-14 Coal production, imports and exports (1980-2016)



Data source: China Statistical Yearbook over years

China’s crude oil production maintains steady growth. After touching 200 million tons in 2010, it remained at the level for six consecutive years; affected by continuous, narrow-range fluctuations at low levels over the past few years, the country has seen its crude oil production in 2016 dropping by 6. 9% compared to the previous year level, which marked the first time ever the country’s annual production decreased to a level under 200 million tons, and the first time ever the annual decrease exceeded more than 10 million tons. With the country turning to be a net importer of oil and crude oil in 1993 and 1996, respectively, China's external oil dependence rocketed to nearly 65% in 2016.

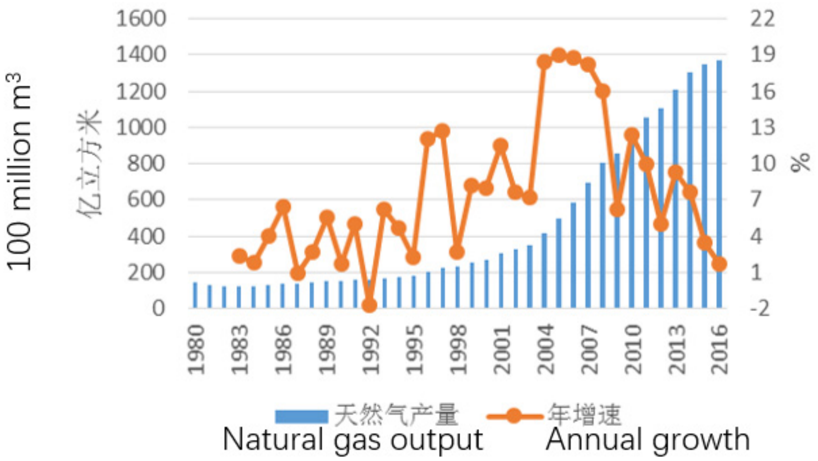
Figure 4-15 Crude oil production and degree of external oil dependence



Data source: China Statistical Yearbook over years

Ever since the start of the new century, China's natural gas production has grown very rapidly, from 27.2 billion m3 in 2000 to 136.9 billion m3 in 2016, at an average growth rate of 10.6% on an annual basis. In 2011, domestic production exceeded 100 billion m3. After 2014, however, due to the slowdown in domestic natural gas consumption growth and the easing of supply and demand in the global natural gas market, imports rose rapidly, which caused a significant slowdown of domestic production.

Figure 4-16 Natural gas production and growth (1980-2016)

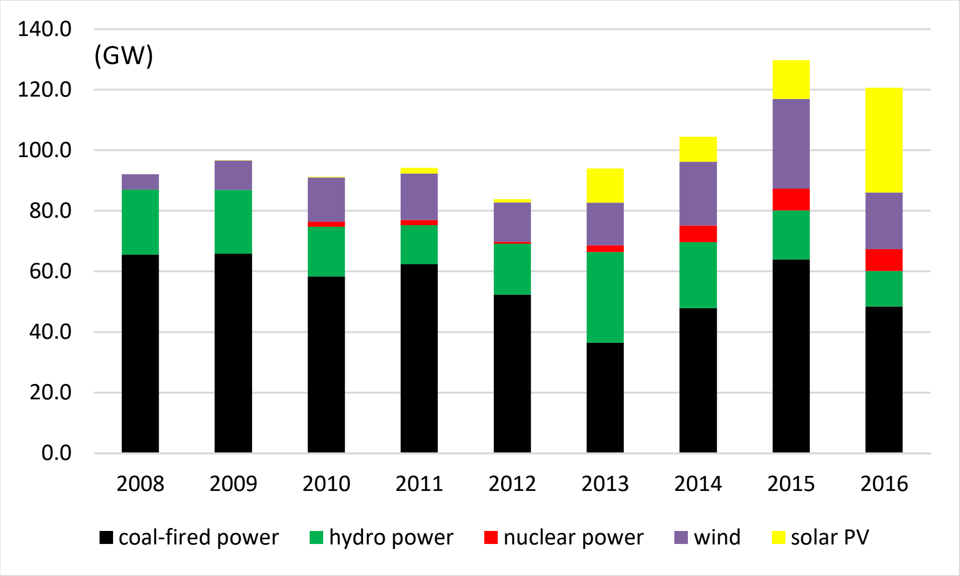


Data source: China Statistical Yearbook over years

Most new installed capacity from renewables

By the end of 2016, the national installed capacity of electricity was 1,650 GW. The annual growth in installed capacity was 121.10 GW, including 48.36 GW of thermal power, 19.30 GW of wind power, 34.54 GW of Solar PV, 11.70 GW of hydropower, and 7.2 GW of nuclear power (see Figure). Renewables made up 55% of added capacity and new investments will continue to focus on non-fossil energy.

Figure 4-17 Annual addition of power capacity of China. Source: China Electricity Council; National Energy Administration for year 2016.



4.3 Status Quo of renewable energy

Deployment of renewable energy

Renewable energy made up the largest share of new capacity installed in 2016, wind, solar PV and hydro totalled 65.54 GW.

In 2016, the previously stated national targets of 15% non-fossil energy in primary energy consumption by 2020 and 20% by 2030 was broken down into provincial targets. This gives local governments a specific target for the share of energy consumption that should be covered by renewables and the progress can be assessed. The central government published annual utilization hours of guaranteed purchase of wind and PV power by region. The compliance with guaranteed hours will be a criterion for approving new wind and solar PV projects there.

Reducing curtailment of renewables

Over the past few years, China's new energy industry witnessed rapid growth and continuously rising share in the energy mix. In 2016, China's installed wind and solar PV power generating capacity reached 149 and 77. 42 million kW, respectively, with their annual energy output accounting for 4.0% and 1.1%, respectively, of the country's total energy output.

In the meantime, serious wind and solar curtailment issues take place in some regions. In 2016, the amounts of wind and solar energy curtailed reached 49.7 and 7.4 billion kWh, respectively, causing huge losses in energy resources, incurring extra costs for new energy power generation and objectively, hindering any further adjustments to on-grid tariffs for new energy-generated electricity.

To address the issue of wind and solar curtailment, Chinese energy authorities have over the past several years taken a series of measures: first is to improve the policy system, for example, by setting up relevant systems, i.e. renewable energy development and utilization target guidance system, guaranteed full-amount purchase system, and wind power surveillance and pre-warning mechanism; second is to optimize development layout, strictly control construction scale in the "three northern regions" where curtailment is serious, and shift the focal areas of wind power development to central and eastern, as well as southern, regions; and third is to optimize dispatching and operation, improve peak load regulation and new energy absorbing capacity, and promote maximum or full power generation from clean energy sources. In 2017, the national competent department of energy further carried out a number of pilot/demonstration projects, including: (1) launching a pilot project on verification and voluntary purchase system for renewable energy green power certificates; (2) conducting a research project on integrated renewable energy application and demonstration zone planning in select regions; and (3) accelerating the development and local absorption of distributed wind power.

In the near future, the national competent department of energy will continue to work on the following tasks: first is to accelerate research on the forming of a quota system for renewable-based power; second is to optimize system dispatching and operation mechanism and clarify implementing measures for making new energy-based power generation a priority; third is to strengthen overall planning and coordination, and optimize the development distribution for wind and solar PV power generation; fourth is to further improve peak load regulation capacity of the power system; fifth is to further the power marketization reform; and sixth is to intensify power demand-side management. Of the above, the power marketization reform and power demand-side management are two top priorities.

On the power marketization reform front, efforts should be directed at (1) pushing forward pilot projects on power spot market construction. In regions like Gansu and West Inner Mongolia where curtailment is serious, efforts should be made to create a level playing field for all sorts of power supplies to compete with each other in a price bidding process. The aim is to fully demonstrate advantages, e.g. low marginal costs, of new energy like wind power, and thus make new energy among the first to be connected to power grid through market auction; and (2) pushing forward development of the auxiliary service market, gradually putting in place an auxiliary service mechanism under which users participate in allocation and the market determines the price in accordance with the principle of "whoever benefits shall bear the costs", and employing market-based measures to raise the enthusiasm of fossil-fuel-based power generation enterprises in taking part in peak regulation.

On the power demand-side management (DSM) front, efforts should be directed at (1) further improving the peak-valley electricity price system, promoting energy storage at valley load, employing market-based approaches to adjust the power consumption patterns of end users, improving system load characteristics, and reducing peak regulation pressure on system; and (2) advocating the use of interruptible load, improving the related electricity pricing system, organizing and coordinating interruptible load users to undertake spinning reserve tasks in peak-load hours, effectively reducing system unit-on capacity, and in consideration of mid-to short-term forecasts, providing capacity guarantees for wind power participation in electric power balance.

Furthermore, the national competent department of energy attaches great importance to giving play to the role of Energy Internet technology in absorbing and promoting wind and solar energy power generation. In recent years, research on the Energy Internet has been increasing. Whilst large-scale substitution of renewable energy with fossil fuels has provided vast development space for the Energy Internet, developing the latter on a large scale also provides new impetus to the energy system reform. The characteristics of new energy, i.e. low marginal costs, short distance to users, huge quantity and scattered distribution, closely match those of the Energy Internet featuring decentralization, flattening and openness. Currently, our focus could be put on taking advantage of the Energy Internet to reshape interaction modes of information, and on giving play to its positive role in power spot market development and power demand-side management, so as to achieve the flexibility in controlling renewable energy resources and thus create more favorable conditions for renewable energy absorption and utilization.

Since 2017, China has made remarkable progress in addressing the issue of wind and solar curtailment. As of the end of June, the amount of wind energy curtailed in China dropped to 23. 5 billion kWh, and average wind curtailment ratio to 14%, representing a 7% decline year on year; the amount of solar energy curtailed in China dropped to 3. 7 billion kWh, and average wind curtailment ratio to 7%, representing a 4. 5% decline year on year. According to the National "13thFive-Year Plan" on renewable energy development, the issue of hydropower, wind and solar energy curtailment is expected to be fully solved by 2020.

4.4 The 13th Five-Year Plan on energy development

The NEA issued the 13th Five-Year Plan on energy in January 2017. The plan sets priorities and targets for energy development and describes major trends for the years 2015-2020.

During the 13th Five-Year Plan period, China's overall thinking for energy planning is as follows: abiding by the strategic thinking of "four revolutions and one cooperation" in energy development, keeping abreast with global energy development trends; adhering to promoting the supply-side structural reform (principal direction), to meeting the needs of socio-economic development and people's livelihood (foothold), to improving energy development quality and benefits (center); focusing on optimizing the energy system, on remedying such insufficiencies as resource environment constraints, low quality and benefits, weak infrastructure and lack of key technology, among others, on cultivating new technology, new industry, new business patterns and models in the energy sector, on improving universal energy service levels; comprehensively advancing the energy production and consumption revolution; striving to create a clean, low-carbon, safe and efficient modern energy system capable of providing a solid guarantee on energy needed for comprehensively building a moderately prosperous society.

In view of the security, resource, environment, technological and economic factors during the 13th Five-Year Plan period, the main targets for energy development in 2020 are illustrated as follows:

Table 4-1 Overall targets set out in the 13th Five-Year Plan on Energy Development

Areas	Specific Contents
Total energy consumption	Total energy consumption is capped at 5 billion tce, and total coal consumption is capped at 4. 1 billion tce. Projected total power consumption of the whole society is 6. 8-7. 2 trillion kWh.
Energy security assurance	Energy self-sufficiency rate remains at 80% or higher; strategic assurance capability for energy security is strengthened, energy utilization efficiency and clean energy substitution level further improved.
Energy supply capability	Energy supply maintains steady growth; national primary energy production remains at approx. 4. billion tce, of which coal, crude oil, natural gas and non-fossil fuel outputs are 3. 9 billion tons, 200 million tons, 220 billion m3 and 750 million tce, respectively. Installed power generating capacity remains at 2 billion kW.
Energy consumption structure	Share of non-fossil fuel consumption rises to 15% or higher; share of natural gas consumption is expected to reach 10%; and share of coal consumption drops below 58%. Coal used for electricity generation as a share of total coal consumption increases to 55%

	or higher.
Energy system efficiency	Energy consumption per unit of GDP decreases by 15% compared to the 2015 level; net average coal consumption rate of thermal power plants drops to 310 g of standard coal per kWh or below; and grid line loss rate is capped at 6. 5%.
Environmental protection and low-carbon aspects of energy	Carbon dioxide emissions per unit of GDP drops by 18% compared to the 2015 level; environmental protection level of the energy industry significantly improves; pollutant emissions of thermal power plants significantly decline; all thermal power units with favorable renovation conditions are expected to achieve ultra-low emissions.
Universal energy service	Public energy service levels significantly improve; access to basic power consumption services is easily available; and the gap in per capita residential power consumption levels between urban and rural households significantly diminishes.

Unlike past energy plans, the "13th Five-Year Plan" on energy development sets out six policy orientations.

First is to pay closer attention to development quality, adjust the stock, make the best of the increment, and actively address the issue of overcapacity. Regarding traditional energy industries with overcapacity or a prospect for overcapacity, in principle, no arrangement should be made to add any new projects in the first half of the 13th Five-Year Plan period. Efforts should be directed towards vigorously pushing forward the upgrading, renovation and elimination of outdated capacity. We should rationally grasp the rhythm of new energy development, focus our efforts on absorbing the stock and optimizing the increment in development. If any new, large-scale base or project is to be built, its market potential should first be identified. Other priorities include forming as early as possible, and improving the monitoring, early warning and control mechanisms overseeing the utilization rates of thermal, wind and solar PV power generation units, and promoting healthy and orderly development of relevant industries;

Second is to pay closer attention to structural adjustment, accelerate the dual replacement process, and push forward green and low-carbon energy development. We should take advantage of the favorable opportunity of relaxed energy supply and demand and quicken our pace in dual replacement of the energy structure. We should focus on lowering the share of coal consumption, accelerate comprehensive treatment of scattered coal, and vigorously advance cascade utilization of coal by quality. We should promote diversification in natural gas resource exploration, development and investment, provide fair access to transportation, storage and receiving facilities, accelerate the price reform, lower utilization costs and expand natural gas consumption. We should devise hydropower and nuclear power development plans way ahead of time, moderately expand construction scale, steadily push forward the development of renewable energy such as wind and solar, and lay the foundation for achieving the non-fossil energy development targets by 2030;

Third is to pay closer attention to system optimization, foster innovative development patterns, and actively create an intelligent energy system. We will deem improving the system peak load regulation capacity as a key measure for remedying insufficiencies in electric power development, accelerate the construction of high quality power sources for peak load shaving, actively develop energy storage, make changes to dispatching operation modes, make breakthroughs at an accelerated pace in operation control technologies, e.g. grid balancing and self-adaptation technologies, and significantly improve the power system's peak load regulating and absorbing capacity for renewable energy. We will intensify power and natural gas demand-side management, and significantly improve user response capabilities. We will vigorously promote integrated energy supply of heat, electricity, chilled water and gas, and accelerate the "Internet Plus" smart energy development;

Fourth is to pay closer attention to market laws, intensify the autonomic regulation of the market, and actively revolutionize energy supply and demand patterns. We should adapt ourselves to the new trend of weakened demand for cross-provincial energy allocation, deal well with the relationship between local energy balancing and cross-regional supply, and prudently study and demonstrate new transmission pathways across different regions. We should employ market-based mechanisms to coordinate the interests of power sending and receiving parties, give play to comparative advantages and strive to achieve mutual benefits and a win-win situation. We should adhere to placing equal emphasis on centralized development and distributed utilization, pay high attention to distributed energy development, vigorously popularize smart energy supply and utilization modes, and cultivate new growth momentum;

Fifth is to pay closer attention to economic benefits, abide by industrial development laws, and enhance the competitiveness of the energy and relevant industries. We will deem a comparatively low comprehensive power utilization cost of the whole society as a key target and measurement criterion for energy development, place more emphasis on economic benefits and strive to form our advantage in producing low-cost energy. We will comply with industrial development trends and laws, gradually lower the tariffs and subsidy standards for wind and solar PV power generation, rationally guide market expectation, promote technological advances and industrial upgrading through competition, and realize healthy and sustainable development of the industry;

And sixth is to pay closer attention to mechanism innovation, give full play to the price regulation mechanism, and promote fair market competition. We will relax control over electricity and natural gas prices in competitive links, gradually form a price mechanism capable of timely reflecting market supply and demand relations and conforming to energy development characteristics, and guide market actors to rationally adjust their energy production and consumption behaviors. We will push forward the implementation of market transaction systems and green financial/taxation mechanisms that are conducive to improving the competitiveness of clean and low-carbon energy sources.

4.5 Recent change in the energy policy framework

New policy:green certificate trading system

As an indispensable support policy for the quota assessment system, green power certificate (Notice on the Trial Implementation of the Renewable Energy Green Power Certificate Issuance and Voluntary Subscription Transaction System, Fa Gai Neng Yuan No. 132 [2017]) is also considered one of the tools forcing various responsibility bodies to fulfill their quota obligations. Starting July 1, 2017, China began to implement a voluntary subscription and green certificate trading system, under which renewable energy power generation enterprises are given green certificates for a certain amount of renewable electricity they produce. Various types of electricity-selling bodies may purchase green certificates through market transactions to fulfill their quota obligations, while renewable energy power generation enterprises gain the corresponding benefits from the green certificate trading.

During the trial implementation stage, enterprises engaged in onshore wind and centralized solar PV power generation may apply for green power certificates for renewable electricity they produce. Any project filing an application for green certificate must already have been registered in the Ministry of Finance's subsidy recipient list. The amount of electricity sold in the green certificate will no longer be eligible for government renewable electricity tariff subsidies. In addition, its selling price should not exceed the government subsidy price (that is, the different between benchmark on-grid tariffs for local renewable electricity and coal-fired electricity).

The introduction of green certificates helps to relieve new energy companies of their long-term dependence on government subsidies. In the short term, the Chinese energy authorities will continue conducting extensive research on a mandatory subscription and green certificate trading system, and plan to launch, at an appropriate time, a green certificate trading system combining both mandatory and voluntary subscription together. In the meantime, they will explore ways to determine renewable electricity subsidy standards and exit mechanisms based on marketized means, in an effort to advance energy transformation in a way having the least overall costs for the whole society.

Orderly development of renewable energy

As for the wind power development, according to the NEA's detection and early warning mechanism for wind power investment (Notice of the NEA on Establishing a Surveillance and Early Warning Mechanism for Promoting Sustainable and Healthy Development of the Wind Power Industry, Guo Neng Xin Neng No. 196 [2016]), the warning degrees are categorized from high to low into three levels: Red, Orange and Green, respectively. The target year of the early warning will be the year after the announcement year. If the actual average annual wind power utilization hours of the year previous to the announcement year are lower than the regional mandatory minimum purchasing hour, then the degree of early warning shall be set to Red directly. For regions that have over 20% of wind curtailment rate one year prior to the announcement year, their early warning result will be Orange or above. If the early warning result is Red, then NEA will not release any development projects within the year the early warning result is released, and localities will suspend approval of new wind power project. If the early warning result is Orange, then the NEA in principle will not release any development projects for the year. The Green result means normal operation. In 2016, early warning results for Jilin, Heilongjiang, Gansu, Ningxia and Xinjiang (including the Production and Construction Corps) were all Red.

According to the Notice, early warning and surveillance results shall be used to provide guidance for provinces and regions in wind power development and investment. Any province, region or municipality receiving a Red result is considered to have a comparatively high risk for wind power development and investment. In that case, the NEA will not release any development construction project within the year the early warning result is released, and localities will suspend approval of new wind power project (including one that has already been included in the year's development plan). Wind power development enterprises are therefore advised to act prudently in constructing any wind power project; and power grid enterprises will stop going through relevant procedures for new grid connection applications. The Orange result suggests there are certain risks involved in wind power development and investment. In principle, the NEA will not release any development project within the year the early warning result is released. The Green result suggests normal operation, meaning local governments and enterprises may rationally proceed with wind power development and investment in accordance with market conditions.

According to the early warning and surveillance results of the Notice on Surveillance and Early Warning Results for Wind Power Investment in 2017, which was released by the NEA in February 2017, **Inner Mongolia, Heilongjiang, Jilin, Ningxia, Gansu, Xinjiang (including the Production and Construction Corps)** were among the areas receiving a Red result, while the rest of the provinces received a Green result. The said Notice further specified that any province (region) receiving a Red result should not approve new wind power development project and take effective measures to solve wind curtailment issues. Power grid enterprises are prohibited from receiving new grid connection applications for wind power development projects (including those that are being constructed, have already been approved or included in the plan) in a province (region) with a Red early warning result. And their local offices shall not issue new power generation business permits for new wind power projects in a province (region) with a Red result.

As for solar PV development, the State specifies designated development projects each year for solar PV power generation (or Top-Runner) technology bases (as per NEA's solicitation of opinions on the Notice of Relevant Requirements concerning Developing Solar PV Power Generation Advanced Technology Bases in 2017, Guo Neng Zong Han Xin Neng No. 47 [2017], aimed to provide impetus to advances in solar PV technology and reduction in costs and tariffs. Localities may, in combination with integrated utilization engineering projects on ecological treatment, facility agriculture, fishery breeding, industrial waste gas site and abandoned oil fields, among others, in coal mining subsidence areas, devise relevant plans for the bases, on the premise that prospective bases must possess a certain scale, be located in a relatively concentrated area, have favourable conditions for power absorption and construction in a unified way. In principle, such bases are to be constructed in the unit of municipality, with a planned capacity of no less than 500,000 kW. All solar PV stations within such bases shall go through a competitive bidding process. In 2016, there were 8 main top-runner bases that adopted a public competitive bidding mode for grid connection. On average, each project saw a 0. 2 yuan price reduction compared to local benchmark on-grid tariff of solar PV electricity. The 8 top-runner bases were located in Hebei (500MW), Shanxi (1GW), Inner Mongolia (1. 5GW), Anhui (1GW) and Shandong (1GW), with a total capacity of 5. 5GW.

Non-Power Comprehensive Utilisation Pilot Projects

Notice on Carrying out a Pilot Program on Winter Clean Heating in Northern Areas Supported by Central Finance (Cai Jian No. 238 [2017])

As for the pilot program on winter clean heating in northern areas, central finance will provide support mainly for the “2+26” cities of the air pollution transmission channel across the Beijing-Tianjin-Hebei Region and its surrounding areas (including Beijing, Tianjin, Hebei Province’s Shijiazhuang, Tangshan, Langfang, Baoding, Cangzhou, Hengshui, Xingtai and Handan, Shanxi Province’s Taiyuan, Yangquan, Changzhi and Jincheng, Shandong Province’s Jinan, Zibo, Jining, Texas, Liaocheng, Binzhou and Heze, and Henan Province’s Zhengzhou, Kaifeng, Anyang, Hebi, Xinxiang, Jiaozuo and Puyang). Main efforts will be directed towards replacing the scattered coal burning mode for heating with clean heating modes, and in the meantime, launching energy-saving renovation of existing buildings. The pilot demonstration period will last for three years. The standard on central finance incentive and subsidy funds will be determined by city size. For example, a municipality directly under the central government may receive up to 1 billion yuan per year, while a provincial capital and prefecture-level city may receive up to 700 and 500 million, respectively, per year.

Pilot cities should implement clean heating renovation from both the "heat source side" and "user side", and form as quickly as possible a clean heating mode that is “mainly driven by enterprise, promoted by government and affordable to residents”. They should follow the principle of “focusing mainly on centralized heating, with the supported of distributed heating”, and “choosing gas and electricity appropriately depending on specific circumstances”, push forward clean renovation of coal-fired heating facilities, promote such heating modes as heat pump, gas boiler, electric boiler and distributed power (gas), and strive to popularize new-type heating modes using distributed renewable energy or a diversity of energy sources, like geothermal energy, air thermal energy, solar energy and biomass, among others. In addition, pilot cities are also expected to improve building energy efficiency at the user end, strictly implement building energy efficiency standards, execute energy efficiency renovation of existing buildings, actively push forward the construction of ultra-low energy consumption buildings, and promote heat meters for heat supply. Detailed renovation contents shall be determined independently by pilot cities.

As for new energy micro-grid development, a total of 28 new energy micro-grid demonstration projects are approved, including 24 grid-connected projects and 4 off grid projects, covering Shandong (5), Zhejiang (4), Hebei (3), Beijing (2), Anhui (2), Gansu (2), Guangdong (2), Shanxi, Jilin, Shaanxi, Guizhou, Shanghai, Fujian, Ningxia and Jiangsu. The newly installed photovoltaic capacity would be 899MW, the newly installed electricity storage would be more than 150MW, and a variety of energy types such as the heat storage, and the wind power are covered as well. Encourage local governments and micro-grid project investment entities to adopt the Public-Private Partnership (PPP) approach, so as to share the responsibility on the construction and operation of new energy micro-grid demonstration projects. After the completion of the internal power generation project within micro-grids, it will be included in the subsidy program of the national renewable energy development fund, and will follow the subsidy policy for distributed renewable power generation.

Notice of NDRC and NEA on Issuing the New Energy Microgrid Demonstration Project List, Fa Gai Neng Yuan No. 870 [2017]

As for the development of new energy microgrid projects, 28 new energy microgrid demonstration projects have so far been approved for construction. Of these projects, there are 24 grid-connected and 4 standalone projects, located in Shandong (5), Zhejiang (4), Hebei (3), Beijing (2), Anhui (2), Gansu (2), Guangdong (2), Shanxi, Jilin, Shaanxi, Guizhou, Shanghai, Fujian, Ningxia and Jiangsu. 899MW of installed capacity is added, and over 150MW of installed capacity for electric energy storage is added. Other types of energy, e.g. heat energy storage and wind power, are also being developed. Incentives are provided for local governments to employ a PPP model in working jointly with microgrid project investors and operators in the construction and operation of new energy microgrid demonstration projects. Upon completion, a microgrid-wide new energy power generation project will be eligible for national renewable energy development fund subsidies in accordance with relevant procedures, and be subject to subsidy policies for renewable energy power generation.

Controlling the excess production capacity and consumption of Coal

In 2016 the NRDC and NEA clarified to cancel, delay approving or postpone construction of a large batch of coal power projects. According to the notice in March 2016[48],those projects that incorporated into the national and lower level energy plans (e. g. Five-year Plan for Energy Sector) but unapproved by the government before 2012 need to be cancelled; by the end of 2017, electricity surplus provinces（after measurements of power supply and demand balance）will delay all coal power projects that only supply power within the particular province they are located in, except for those projects involved in civil district

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[48] http://www. ndrc. gov. cn/zcfb/zcfbtz/201604/t20160425_798979. html

heating CHP (includes demonstration projects approved by the national government); those local-consume coal power projects in electricity surplus provinces that have not started the construction process yet should be postponed before 2017; those are currently under construction should apply appropriate adjustment to their construction schedule, hence to properly control the commissioning pace.

In August 2016, 15 projects that are not qualified for approval were cancelled with a capacity of 12.4 GW by NEA. Even some of the named projects may currently under construction, they should be put into a halt immediately. This set of projects was involved into annual construction plan between 2009 and 2012. Provinces involved include Jilin, Shanxi, Shandong, Shaanxi, Sichuan, Jiangxi, Guangdong, Guangxi and Yunnan.

In October, 2016, the NEA halted all construction and approval processes for coal power plants in 28 provinces (only four provinces in China including Anhui, Hubei, Hainan and Jiangxi were excluded). All projects in any of the 28 provinces with thermal overcapacity designated "Level Red" are suspended indefinitely. If and when the provinces' overcapacity risk level returns to a designated "Level Green", construction can resume. This measure is a complete freeze that is applied to the project approval process as well as any plants currently under construction.

The result published in 2017 on early warning of risk on planning and construction of coal-fired power plants in 2020shows that, among the 32 provincial grid areas (including East and West IMAR), there are 25 areas with red-degree warning, which is the highest warning degree, the warning degrees of Hunan and Hainan are green, and the warning degrees of Hunan, Hubei, Jiangxi, Anhui are orange, there is no relevant warning information on Tibet Autonomous Region. Compared with the early warning of risk for coal power planning and construction in 2019, the warning degrees in 9 regions are enhanced, and 6 regions are declined. In addition, compared to the notice of coal power planning and constructing in 2019, the 2020 notice emphasized that it is necessary to effectively and orderly prevent and resolve the risk of coal power overcapacity, in accordance with the moderate strictness principle. As for the provinces with red or orange-degree warning, it is necessary to suspend the approval and the construction of new self-use coal power projects including self-use coal fired units, the same below), and under the guidance of the nation, to reasonably arrange the commissioning schedule of coal power projects which are under construction now. Provinces with green-degree warning shall also fully consider factors such as the capacity of linkage between provincial (regional) power grids, and orderly approve and commence the construction of coal power projects.

Table 4-2 Coal-fired power planning and construction risks and early warning for 2020

No.	Region		Early warning indicator of economic efficiency for coal-fired power construction	Early warning indicator of coal-fired installed capacity adequacy	Resource constraint indicator	Early warning result of risks involved in coal-fired planning and construction
1	Heilongjiang		Green	Red	Green	Red
2	Jilin		Green	Red	Green	Red
3	Liaoning		Orange	Red	Green	Red
4	Inner Mongolia	Eastern Inner Mongolia	Green	Red	Green	Red
5		Western Inner Mongolia	Green	Red	Green	Red
6	Beijing		-	-	Red	Red
7	Tianjin		Orange	Red	Red	Red
8	Hebei		Green	Red	Red	Red
9	Shandong		Red	Red	Red	Red
10	Shanxi		Red	Red	Green	Red
11	Shaanxi		Green	Red	Green	Red
12	Gansu		Red	Red	Green	Red
13	Qinghai		Red	Red	Green	Red

No.	Region	Early warning indicator of economic efficiency for coal-fired power construction	Early warning indicator of coal-fired installed capacity adequacy	Resource constraint indicator	Early warning result of risks involved in coal-fired planning and construction
14	Ningxia	Orange	Red	Green	Red
15	Xinjiang	Green	Red	Green	Red
16	Henan	Green	Orange	Green	Orange
17	Hubei	Red	Orange	Green	Orange
18	Hunan	Green	Green	Green	Green
19	Jiangxi	Green	Orange	Green	Orange
20	Sichuan	Red	Red	Green	Red
21	Chongqing	Red	Red	Green	Red
22	Tibet	-	-	-	-
23	Shanghai	Green	Red	Red	Red
24	Jiangsu	Green	Green	Red	Red
25	Zhejiang	Green	Red	Red	Red
26	Anhui	Green	Orange	Green	Orange
27	Fujian	Red	Red	Green	Red

No.	Region	Early warning indicator of economic efficiency for coal-fired power construction	Early warning indicator of coal-fired installed capacity adequacy	Resource constraint indicator	Early warning result of risks involved in coal-fired planning and construction
28	Guangdong	Green	Red	Red	Red
29	Guangxi	Red	Red	Green	Red
30	Yunnan	Red	Red	Green	Red
31	Guizhou	Red	Red	Green	Red
32	Hainan	Green	Green	Green	Green

Thermal power flexibility pilots

In June 2016, the NEA issued "Notice Regarding Issue of Thermal Power Flexibility Retrofit Pilot Projects". The notice announced 16 pilot projects that will showcase how to improve thermal power plant flexibility. Increased thermal power plant flexibility will contribute to reducing curtailment of renewable energy. The selected units had a total installed capacity of 12. 37 GW. Subsequently six more projects with a total capacity of 4. 02 GW were added to the pool of pilot projects. The provincial distributions of this total capacity of 16. 39 GW are divided as follows: Liaoning (4. 15 GW), Jilin (5. 22 GW), Heilongjiang (2. 00 GW), Gansu (660 MW), Inner Mongolia (3. 12 GW), Guangxi (640 MW) and Hebei (600 MW). The peak load regulation capacity would be increased by 20% for cogeneration units and by 15-20% for condensing units. Therefore, the minimum load would down to 40-50% of rated capacity for cogeneration units and 30-35% for condensing units. The pilot projects will benefit from international cooperation and technology exchange. Power plants which are suitable for retrofitting are expected to reach a level of flexibility that is on par with advanced international power plants. At this level, the minimum load for cogeneration units operating under condensing condition can be held at 20-25% in stable combustion without adding fuel.

New progress on power system reform

Since March 2016, a total of 12 provincial or municipal grids and the North China regional grid were included into the power transmission and distribution pricing reform pilot; these power grids are Beijing, Tianjin, Jinan (South of Hebei), Jibei (North of Hebei), Shanxi, Shaanxi, Jiangxi, Hunan, Sichuan, Chongqing, Guangdong, Guangxi and Northern China Regional Power Grid. With the addition of 6 provinces that already enlisted in the pilot programs, i. e. Western Inner Mongolia, Anhui, Hubei, Ningxia, Yunnan and Guizhou, the scale of pilot projects now covers 18 provincial grids and one regional grid. In September of 2016, the pilot reform program of the power transmission-distribution tariff was launched in 14 provincial power grids including Eastern Inner Mongolia, Liaoning, Jilin, Heilongjiang, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Henan, Hainan, Gansu, Qinghai and Xinjiang. Region-wide reforms are planned to be implemented in Tibet, Eastern, Central, Northeastern and Northwestern regional power grids in 2017.

In June 2016, the NEA released the "Notice on Promotion of Involvement of Electricity Storage in the Compensation (Market) Mechanism Pilot Projects for Electricity Auxiliary Service in "Triple-north" Area". This is a follow-up policy of "Guidelines Regarding the Promotion of "Internet+" Smart Energy [2016] No. 392" and "Notice of Request to Accomplish Renewable Energy Consumption Works in the "Triple-north" Areas [2016] No. 39". It is required that: Based on the principal, there are no more than 5 electricity storage facilities that can be involved into the compensation mechanism pilot projects for auxiliary services of electricity peak load regulation and frequency regulation. Such involvement is designed for exploring the technical impacts and commercial applications of electricity storage in peak load regulation and frequency regulation within the power system. The investments from power generating companies, power supply enterprises, power users and electricity storage companies on electricity storage facilities are encouraged. The electricity storage facilities that are constructed at power generating side can participate in auxiliary services market trading as independent body, those constructed at user side can be seen as distributed power resources and sold to nearby power users. For electricity storage facilities built at the user side that reach a certain level of scale, they can be treated as independent market body and participate depth peak load regulation.

On December 2016, the "Pricing Method for Provincial Power Transmission and Distribution Tariff (Trial)" was issued to define the calculation methodology and boundary conditions of provincial level power transmission and distribution tariff. Coupling with the previously promulgated "Supervision and Inspection Measures Regarding Cost of Transmission and Distribution Pricing System", the country has established a scientific, standardized and transparent framework for supervision and management system of transmission and distribution tariff in the first step.

Per NDRC document No. 9 and its supporting documents, the aim of China's electric power market development is to "gradually put in place an electric power market that is capable of avoiding risks through middle- and long-term transactions, of discovering prices through the spot market, and has a full array of transaction varieties and a complete set of functions, and to gradually form in China a market system characterized by full competition, openness and orderliness, as well as healthy development." Per the Basic Rules for Middle- to Long-Term Electric Power Transactions (for trial implementation) (Fa Gai Neng Yuan No. 2784 [2016]) and the Notice on Opening Development Power Consumption Plans in an Orderly Manner (Fa Gai Yun Xing No.294 [2017]), which were jointly issued by NDRC and NEA in 2017, localities should, while taking account of their actual conditions, quicken their pace in the opening of development power consumption plans in an orderly manner. On the basis of middle- to long-term transactions, which now comprise a majority of all transactions, local governments must actively foster innovation, enrich transaction varieties, and steadily push forward spot transaction to gradually form an electric power market that is capable of avoiding risks through middle- and long-term transactions, of discovering prices through the spot market, and has a full array of transaction varieties and a complete set of functions.

5 Main challenges for the Chinese energy system transition

China is now entering a new development stage when energy consumption growth 'shifts into a low gear'; the pressure on supply assurance is significantly relieved; and supply and demand remains in a relatively loose state. However, there still exist some deep-level contradictions with the energy structure, and with the related systems and mechanisms, which have become important factors affecting energy transformation and sustainable development. These contradictions are mainly reflected in the following aspects:

Structural overcapacity of the conventional energy sector poses a serious challenge.

Overcapacity of the coal industry has led to a severe imbalance of supply and demand. A significantly low level of average utilization hours of coal-fired power generating units, which appears to be declining even further, results in low equipment utilization efficiency and greatly increased energy consumption and pollutant emissions. Primary processing capacity of crude oil is in surplus; its capacity utilization rate remains low at less than 70%. Nevertheless, production capacity of high-grade clean oil products is still inadequate.

Renewable energy development faces multiple bottlenecks.

The guaranteed full-amount purchase policy for renewable energy is yet to be effectively implemented. The power system’s insufficient peak load regulation capability and lack of a complete cost compensation mechanism governing dispatching operation and peak regulation has caused it hard to conform to the requirement of large-scale grid connection and absorption of renewable energy. Wind, hydropower and solar curtailment have become serious issues in some regions. A mechanism, which is conducive to incentivizing operators engaged in wind and solar PV power generation to reduce their costs and quicken their pace in distributed power development through technological advances, is yet to be formed. Until then, diversification in renewable energy development patterns will be constrained.

The consumer market for natural gas is yet to be developed.

Prompt efforts must be made to expand new consumer market for natural gas, given the problem of coexistence of notably low natural gas consumption level and its periodic excess supply surplus. There exist multiple barriers for expanding the natural gas consumption, e.g. incomplete infrastructure, low density of pipeline network, severe shortage of gas storage and peak load regulation facility, and relatively high transmission and distribution costs. Other issues include lack of a complete market mechanism, difficulty in importing natural gas from the global market at the time of low prices, and relatively high natural gas price levels in general, etc. With the decreasing coal and oil prices, the low-price appeal of natural gas has been further weakened, which limits the expansion of the natural gas consumer market.

Clean energy substitution remains an arduous task.

In some regions, environment carrying capacity of energy production and consumption is close to their upper limits. Air pollution situation is extremely serious. The share of coal in final energy consumption exceeded 20%, which is 10% higher than the global average level. Costs of clean energy substitution solutions, like "substituting coal with gas and electricity", remain high, making popularization of clean briquette very difficult. Huge amounts of coal are still burned by small-sized boilers, furnaces and household equipment, causing serious pollutant emissions. The utilization rate of high-quality clean oil products remains at a low level. Renovation and upgrading of transportation oil consumption is highly expected.

The overall energy system efficiency is still low.

Integration, mutual complementation and cascade utilization degrees of different energy supply systems for electric power, heat and gas are quite low. Other problems include widening electricity and natural gas peak-valley differences, severely insufficient system peak load regulation capability, absence of a fully-fledged demand-side response mechanism, and continuously declining system equipment utilization rates as supply capacity is usually designed to meet maximum loads. For the north-western region where wind and solar energy power generation is concentrated, long-distance, large-scale power transmission entails huge amounts of coal for the purpose of peak load regulation, which leads to low proportions of clean energy transmitted and low system utilization efficiency levels.

Sharp contradictions arise during the course of energy resource allocation across different provinces and regions.

In contrast to most energy resource-rich regions, which still maintain the development inertia of producing at large scale and relying mainly on external transmission, major energy-consuming regions have experienced slow growth in demand, diminishing market space and paid closer attention to economic benefit and controllability aspects of energy acquisition, hence decreased enthusiasm in general in accepting energy transmission from other regions. Due to the worsening of interest contradictions between energy-sending and receiving regions, optimization and allocation of clean energy is facing obstacles throughout the country. Some cross-provincial/regional energy transmission pathways are confronted with the risks of inefficient operation or even lying idle.

Systems and mechanisms are yet to be further adjusted to conform to the energy transformation.

A lot still needs to be done in relation to harmonization and coordination of energy pricing, taxation, financial and environmental protection policies, as energy market system construction lags far behind, and the role of market in resource allocation is not fully recognized. Other issues include incomplete pricing system, lack of cost compensation and related pricing mechanisms for natural gas and electric power peak regulation, absence of a fully-fledged price adjustment mechanism that is both scientific and flexible, and inability to adjust to new requirements of the energy revolution.

The Economy and Several Provinces heavily rely on Coal Exploitation

The economy of China, especially the Coal dominated provinces heavily depend on the production of coal which is the strongest obstacle for energy transition. Without the energy sustainable development path, China would never escaped from the current vicious circle of economy development. Hence, energy transition must solve the problems caused by economy, from national level to the provincial level.

Part 2:

Energy transition scenarios

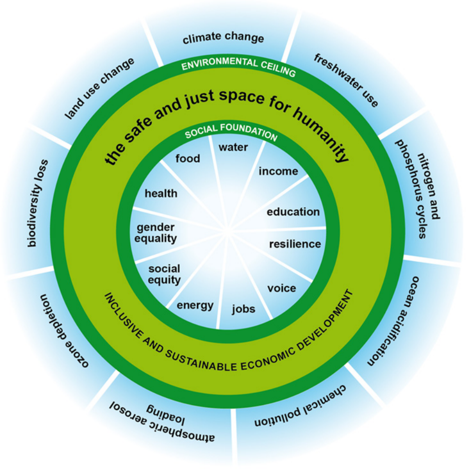
6 CREO's Rationale

The two centenary goals for China – to become a moderately prosperous society before 2020 and to become a "prosperous, strong, democratic, culturally advanced, harmonious and beautiful" society before 2050 are the twin overarching visions guiding China's development. They represent opportunities for the Chinese people to pursue a better life in all its aspects. The vision also includes the concept of balanced, and adequate, development; sustainable development, that respects hard ecological constraints. These constraints are local, like the air quality, include land use, and freshwater use; and they are global, like limits on emissions that cause climate change, and the need to protect biodiversity.

Economic policies in the 21st century must reflect these development principles, and aim to realise this vision. While energy fuels economic development, the way energy is produced must respect ecological constraints to ensure development is sustainable in attempting to realise this vision.

These principles are not unique to China, but also part of the international discourse on modern economics and development policies. British economist Kate Raworth outlined a similar vision in "Doughnut Economics" and expressed it this way: "Humanity's 21st century challenge is to meet the needs of all within the means of the planet. In other words, to ensure that no one falls short on life's essentials (from food and housing to healthcare and political voice), while ensuring that collectively we do not overshoot our pressure on Earth's life-supporting systems, on which we fundamentally depend – such as a stable climate, fertile soils, and a protective ozone layer".

Figure 6-1 The Doughnut economy, created by Kate Raworth, expressing the social and planetary boundaries



In our analyses, we take as starting point that a sustainable energy system is the precondition for a sustainable economic development. We adapt the "Five-in-One" overall development layout, and the "Four Comprehensives" to develop the framework for the energy system transformation.

Theoretical foundation and meaning of the three-line development concept

The *Outline of the 13thFYP for Economic and Social Development of the People's Republic of China* points out the future development direction and overall development strategy of China between 2015 and 2020. In due course, the plan will contribute to the implementation of the *Four Comprehensives*:1) comprehensively complete the building of a moderately prosperous society, 2) comprehensively deepen reform, 3) comprehensively implement the rule of law and 4) comprehensively enforce strict party discipline.Development must be a top priority, to lay a solid foundation to realize the second objective of *Two Centenary Goals* while realizing the first Centenary Goal.From an economic and social development angle, we aim to establish and implement the *Five Development Ideas*, which cover *innovation, coordination, green, opening-up and sharing* to progress the*Five in One*concept, that is: economic construction, political construction, cultural construction, social construction and ecological civilization construction.

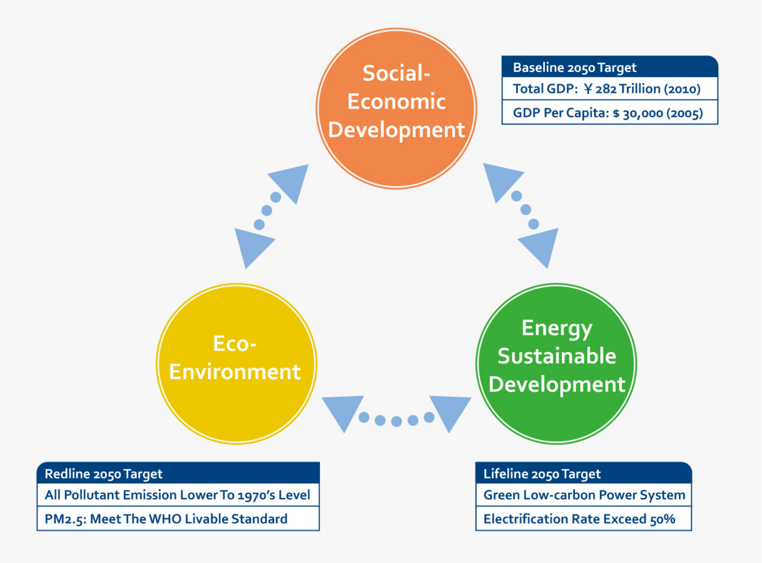
China is on a new development path, at the heart of which is the concept of the ecological civilization: "With the rising of ecology the civilization flourishes, while with the decline of ecology the civilization perishes". Since the 18th National Congress of the CPC, the ecological civilization construction has been put in a strategic position for the *Five in One* overall layout of Chinese socialism. Meanwhile, among the *Five Development Ideas*, green development has become an important underpinning concept of economic and social development in the 13thFYP period and even in the longer term. Green development, as an important new development concept, advocates a green lifestyle while guiding green economic production. Good ecological environment is the most equitable public good as well as the most inclusive for the well-being of the people. Environmental degradation has become one of the most serious problems that the Chinese society and even the world faces today. It is also an important focus since once the ecological environment is destroyed, higher governance cost will be required and even social decay may occur, which will significantly influence people's quality of life. For this reason, General Secretary Xi Jinping stressed that we should protect the ecological environment like we protect our eyes and treat the ecological environment like it's our lives. "Green mountains and clear water are as good as mountains of gold and silver", symbolizes the importance of environmental protection in China's sustainable development.

In promoting the *Five in One* overall layout of economic construction, political construction, cultural construction, social construction and ecological civilization construction, the economic construction is the top priority, and the ecological civilization construction is the ultimate goal. If the economy grows with deterioration of environment, it is not *Five in One*. In China, economic construction and energy development are closely linked at present since China still has a high-carbon energy structure, with the total energy consumption still ranking the first in the world. Under this structure, China's economic construction would definitely result in high emissions and pollution. Therefore, it is an inevitable choice to guide and restrict China's energy system transformation with ecological civilization construction, taking the path of sustainable energy development and support economic construction. In other words, if China takes a new path of economic development, it must take a new path of energy development, too.

The consensus and vision on China’s energy development direction and overall strategy serve as the foundation of the *Three-Line development* concept. The Three-Line refers to the bottom line, the red line and the lifeline. For the bottom line, economic development is the top priority. By 2050, China's economic and social development should go beyond a bottom line. With GDP as an indicator, per capita GDP should reach the standard of moderately developed countries by then, and the bottom line of GDP is RMB 282 trillion. For the red line, it is imperative to recover clear water and blue sky; it is an un-traversable line of the ecological environment. The quantitative standard is that emissions of pollutants caused by energy production and consumption, including CO_2 emissions, should decrease to the level of the late 1970s or early 1980s, and PM2.5 should reach the liveable standard specified by World Health Organisation. For the lifeline, economic development cannot be separated from energy support, with ecological civilization construction as the primary task for economic development, and green and low-carbon power as the lifeline of coordinated development of economic society and ecological environment. In short, economic development is the bottom line, ecological environment is the red line and green power is the lifeline, which determines that China’s path of energy transformation and development by 2050 is high-penetration renewable energy development.

Specifically, we have set-up the “Three-line” development concept with a social and economic “baseline”, a “red line” with the ecological boundaries for the development and the green “lifeline” which is the enabling sustainable energy development making it possible to fulfil the baseline requirements without overstepping the red line.

Figure 6-2 The “Three-line” development concept as framework basis for the scenario development in CREO



7 Research questions and scenario design

For this year's outlook, we have focused on two questions. The first is related to the development path already set out by the Chinese government, the second is related to the joint global commitment to sustainability:

Question 1: What is the development trend for the Chinese energy system, if the policy already stated is vigorously implemented?

Question 2: How can China comply with the Paris agreement using the domestic strategies and priorities?

We developed and analyse two scenarios to answer these questions. For both scenarios, we want to investigate how the socio-economic framework conditions, the technology development trends, and specific policy measures can create a pathway for transition of the Chinese energy system.

The time frame for the analyses is the period from 2016 to 2050. By 2050 the transformation of the energy system should largely be complete under the vision of a fully developed China. After 2050 the development pathway should be smoother.

For question 1 we look at key policy measures which influence the development of the energy system and that are in place, or decided, today. We assume as a starting point, that these existing policies will be implemented proactively and efficiently. Then, through model analyses we look step-by-step at the energy system transition.

For question 2 we add the additional constraint that China should have quick and ambitious CO_2 reductions, to deliver compliance with the Paris agreement as part of the global commitment to mitigate anthropogenic climate change.

The questions and assumptions are represented in two scenarios: The Stated Policies scenario and the Below 2 °C scenario. The scenarios are consistent with development roadmaps for the entire Chinese energy system, and comply with their framework conditions and policy constraints.

The model analyses use CNREC's energy system models. These are bottom-up, and help to define energy system characteristics required to ensure sufficient energy demand, help outline where transformation is needed. There is a focus on power and district heating in the modelling. This is because these underpin renewable energy development, through the integration of variable power production into the overall system in a cost-efficient manner. Hence, we use a detailed dispatch model on a provincial level, which is able to dispatch the power and district heating system on an hourly basis, based on least cost optimisation. The model is also able to make least cost investment decisions in new production capacity based on information regarding investment cost and operational cost for different types of power generation. As a supplement to these models we use a Computerised General Equilibrium (CGE) model of the Chinese economy to estimate the impact on GDP and job creation.

The model represents 31 provinces in China including the four provincial level municipalities. Due to the scope of key data sources for populating the model, the model does not include Hong Kong and Macau SAR, nor Taiwan province. The map colours indicate where groups of regions are within the same overall grid region. Inner Mongolia is divided into the Eastern and Western parts creating a total of 32 distinct geographical regions in the model.

Figure 7-1 Map of the regional representation of China

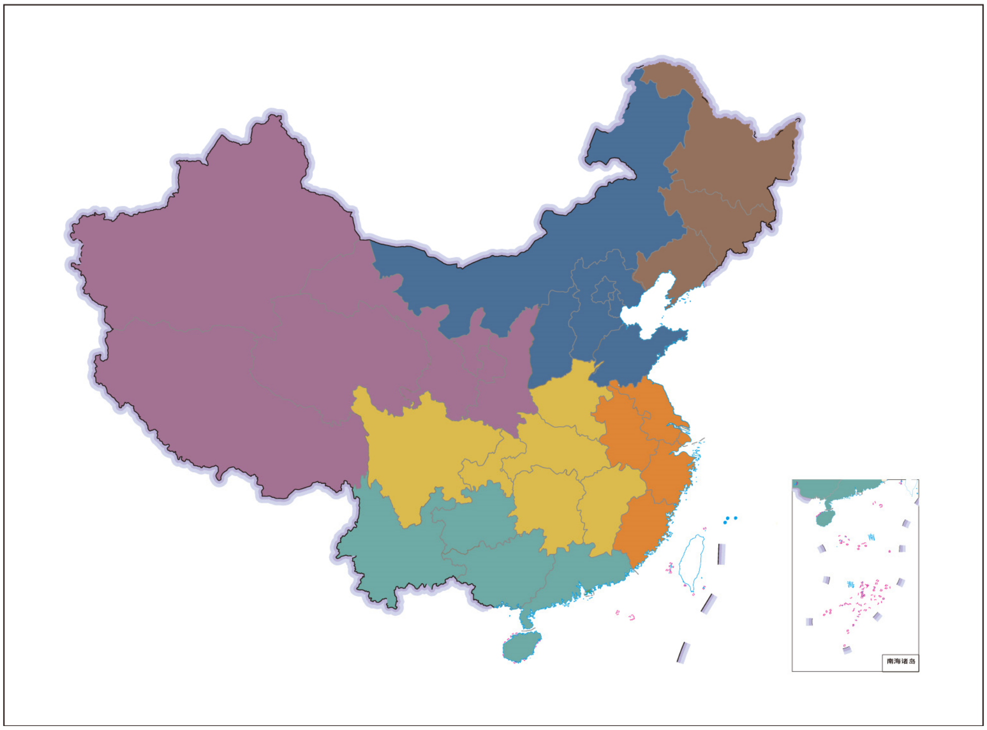
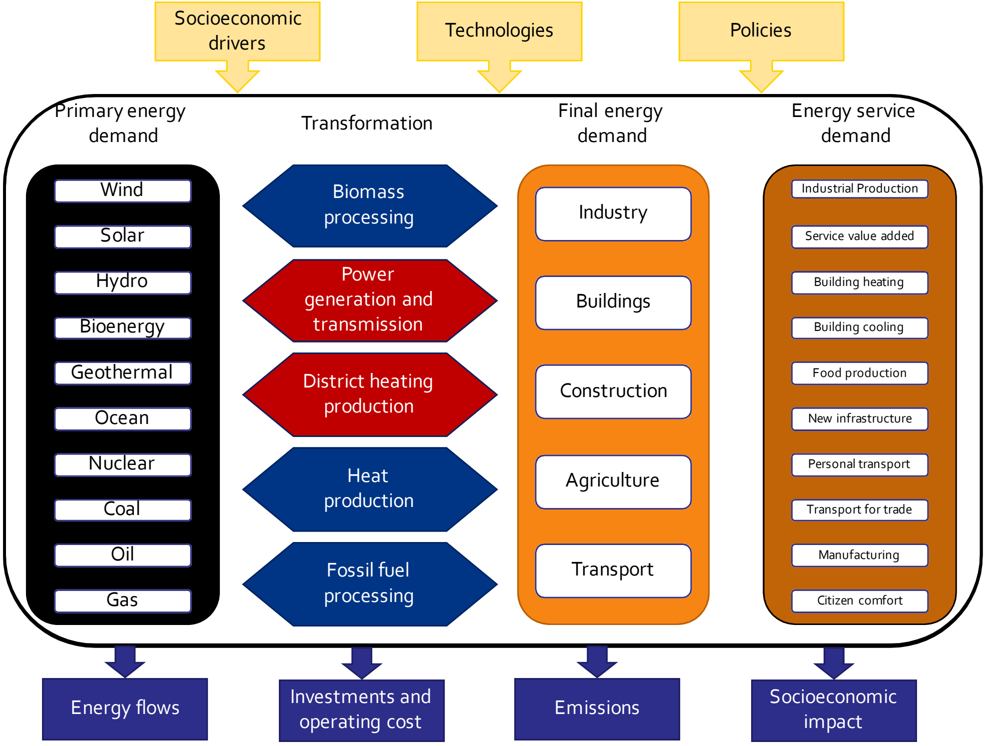


Figure 7-2 The energy system modelled in the CREO scenarios – from energy demand to fuels.



The system development is driven by socioeconomic drivers, technology development and specific policy measures. The outputs from the scenario modelling are energy flows, economic parameters, environmental factors and socioeconomic impact

Scenario consistency in the power and district heating sector is ensured using the EDO model (Electricity and District Heating Optimisation). EDO is a combination of a capacity expansion model and an optimal unit commitment and economic dispatch model. Essentially, the model finds the cost-optimal solution for the power and district heating sectors by minimizing total costs including capital, operation and maintenance, and fuel costs, subject to constraints imposed on the solution such as specific targets or polices that must be achieved.

This study is not an attempt to use the model to find the least-cost scenario. Rather the cost minimization aspect of the model is used to provide a solid foundation and reasonable proof using a bottom-up approach in the scenario projections, from the vision or narrative which defines the scenario. Using least-cost optimisation is a short-cut to replicate the behaviour of the energy industry in between the policy imperatives laid out in established policies and scenario assumptions. While a fully-fledged least-cost optimisation approach has a strong normative internal justification of the scenario outcomes, it will generally point towards 'corner solutions' where a limited selection of technologies is chosen on the basis of cost differences between technologies. These cost differences are highly uncertain in the long-term. Different stakeholders in the market have different expectations for their development which leads to stakeholders pursuing a more diverse range of technologies and projects, in modelling, these stakeholders all share the same assumptions about how the future will unfold.

Meanwhile, experience with least-cost modelling in energy transition studies suggest that the solution space is 'flat'. This means that the cost difference between several feasible pathways towards achieving the scenario objectives may be low. In many cases the cost differences are lower than the inherent uncertainty of key input parameters, especially in the long-term. Policy and scenario assumptions are thereby implemented to guide the model results towards the scenario narrative, rather than allowing the least-cost algorithm to solely determine the capacity mix which achieves the scenarios' overarching objectives. This guidance is described further in Chapter 8 and comprises of a combination of targets reflecting specific polices, implication assessments, and targets to directthe scenario to follow the central narrative of the scenarios.

When looking at renewable energy development, the power sector has a special role. Firstly, some of the main RE technologies, wind and solar PV, are electricity generators. Secondly, the variable power production from these resources gives special conditions and challenges for the dispatch of the power system with significant influence on the operation of the thermal power plants and interprovincial transmission lines. In a Chinese context, the linkages between power and heat production must also be considered when representing the operation of the power system. Finally, it is important to be able to reflect the development of a power market with a cost-efficient dispatch of the generation and transmission of electricity, in order to add insights for the ongoing process of power market reform in China.

Model development since CREO 2016

Several improvements have been made to the models, since the finalisation of CREO 2016. These impact on this years' results and the analytical capability available in the CREO 2017 report. Below, key improvements are highlighted:

Electricity and District heating Optimisation model (EDO)

Thermal plant enhancements:

- **Retrofitting plants** – Existing capacity can change technical and economic characteristics through retrofit investments. Used in CREO 2017 for retrofitting thermal power plants' flexibility characteristics.
- **Power plant flexibility** – enhanced thermal plant representation to include options of bypass, overload and optimized CHP output.

Renewable plant enhancements:

- **Wind power technology model** – replacing generation profiles as input, with wind speed timeseries; associating turbine power curve and hub height to yield output; Smoothing wind timeseries by deployment area; Enables representation of options, e.g. low-wind vs. regular turbines.
- **Solar PV technology model** – replacing exogenous production profiles with direct and indirect radiation time series, to be combined with panel efficiency characteristics and orientation
- **CSP with storage** – CSP technology model updated to allow endogenous use of storage, replacing exogenous discharge patterns.

Other enhancements:

- **Transmission flow constraints** allow for gradual market opening
- **Supply cost curve** for technologies with finite capacity potential

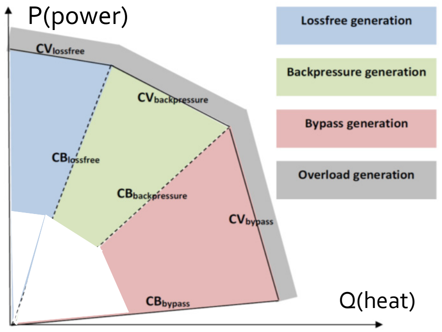
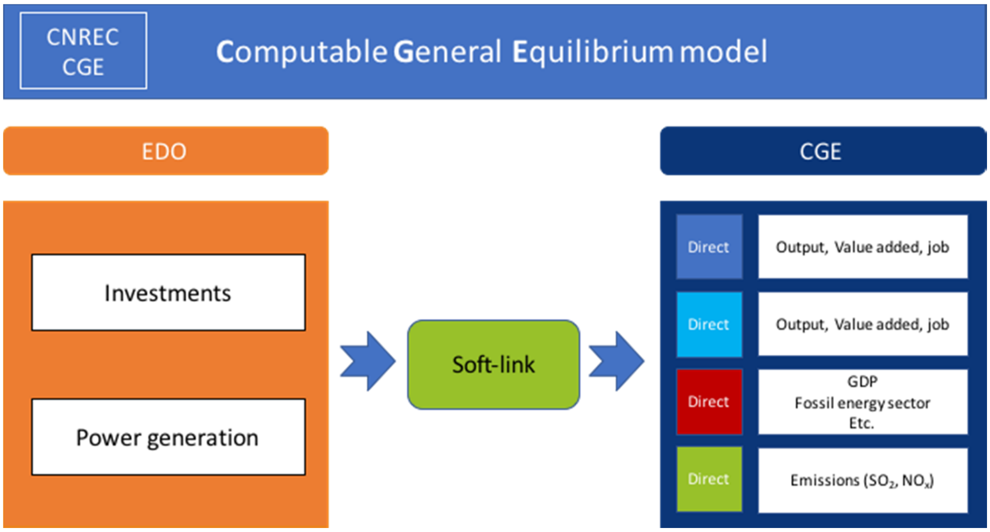


Figure 7-3 Feasible power-heat operating envelope of a generic thermal CHP plant

The EDO model and CGE model are soft-linked by passing renewable energy investments and power generation data from EDO to CGE. The investment is used as capital input in the production function of renewable energy power generation. In addition, the power generation in TWh from EDO model is imposed as the target production amount of renewable energy power generation in the CGE. These two boundaries not only affect the economic scale of RE sectors but also the scale of fossil-fired power generation since the total electricity demand of the whole society is similar in the scenarios. Therefore, more investment in RE and more output from RE will implicitly suppress the growth space of fossil-fired power generation, the underlying investment behaviours towards these sectors and the stimulating effects on the upstream industries.

Figure 7-4 The soft-link framework of CGE and EDO models



8 Main assumptions

8.1 Carbon constraints

The carbon emission constrains for the Stated Policies scenario is based on China's current carbon emission intensity target: a reduction of 40%-45% and 60%-65% in carbon intensity by 2020 and 2030 respectively. These targets are for the entire Chinese economy, but here we apply the same reduction to the energy system. The results from the scenario modelling show that these targets are not actual constraints on the energy system development due to other constraints and assumptions.

For the Below 2°C scenario we base the carbon constraints for the energy system on several different simulations from the IPCC AR5 database with >66% chance of staying Below 2°C warming.

Table 8-1 Carbon constraints for the two scenarios

Carbon constraints for the two scenarios				
Scenario	**Parameter**	**2020**	**2030**	**Year 2050**
Stated Policies Scenario	Carbon intensity	40-45%	60-65%	-
Below 2°C Scenario	Carbon cap (Mt CO2)	9,000	8,000	3,000

The CO2-development pathway for the two scenarios is subdivided into a cap for power and district heating and a cap for other sectors. This subdivision allows for the implementation of an explicit cap in the EDO model as this only covers power and district heating.

Power and DH CO2 cap = Total CO2 cap –CO2from other sectors

In the Below 2°C scenario the power and district heating CO2 boundary is implemented by subtracting that scenario's emissions from of sectors outside of power and district heating from the total CO2 budget.

Table 8-2 Carbon budget for the Below 2°C scenario (million tons).

	2 020	**2 030**	**2 040**	**2 050**
Carbon budget for the energy sector	9 000	8 000	5 500	3 000
Power and DH carbon budget	2 862	2 748	1 798	1 282

In the Stated Policies scenario, the CO2 limitation is not imposed as a modelling constraint explicitly, since CO2 reductions in the other energy sectors, leave significant headroom.

8.2 Carbon market development

In both scenarios, the CO2-price expected to arise from the national emissions trading system is implemented as a CO2 emissions cost.

In the Stated Policies scenario, this means that the Chinese national ETS creates a disincentive for CO2 emissions from the power sector with an effect of 30 RMB/ton starting in 2017. This rises to 50 RMB/ton by 2020 and to 100 RMB/ton in 2030. From here the price stagnates in the Stated Policies scenario, while it increases further to 200 RMB/ton in 2040in the Below 2°C scenario. These price levels are discussed further in Part 3 of this report.

Table 8-3 Assumed price of emitting CO2 in the two scenarios (RMB/ton)

	2017	*2020*	*2030*	*2040*	*2050*
Stated Policies	30	50	100	100	100
Below 2 °C	30	50	100	200	200

In the Below 2°C scenario, this CO2 emission disincentive should be seen as a minimum level, which is increased as a modelling output to the level necessary to achieve the annual CO2 emissions limit.

8.3 Policy targets and instruments

Short-term (13th five-year plan)

Several targets and guidelines laid out in the 13thfive-year plan (FYP) are implemented in the scenarios.

Table 8-4 Overall targets set out in the 13thFYP on Energy Development (2015-2020)

Areas	Specific Contents
Total energy consumption	Total energy consumption is capped at 5 billion tce, and total coal consumption is capped at 4. 1 billion tce. Projected total power consumption of the whole society is 6. 8-7. 2 trillion kWh.
Ensuring energy security	Energy self-sufficiency rate remains at 80% or higher; strategic assurance capability for energy security is strengthened, energy utilization efficiency and clean energy substitution level further improved.
Energy supply	Energy supply maintains steady growth; national primary energy

capability	production remains at approx. 4. billion tce, of which coal, crude oil, natural gas and non-fossil fuel outputs are 3. 9 billion tons, 200 million tons, 220 billion m3 and 750 million tce, respectively. Installed power generating capacity remains at 2 billion kW.
Energy consumption structure	Share of non-fossil fuel consumption rises to 15% or higher; share of natural gas consumption is expected to reach 10%; and share of coal consumption drops below 58%. Coal used for electricity generation as a share of total coal consumption increases to 55% or higher.
Energy system efficiency	Energy consumption per unit of GDP decreases by 15% compared to the 2015 level; net average coal consumption rate of thermal power plants drops to 310 g of standard coal per kWh or below; and grid line loss rate is capped at 6. 5%.
Environmental protection and low-carbon aspects of energy	Carbon dioxide emissions per unit of GDP drops by 18% compared to the 2015 level; environmental protection level of the energy industry significantly improves; pollutant emissions of thermal power plants significantly decline; all thermal power units with favourable renovation conditions are expected to achieve ultra-low emissions.
Universal energy service	Public energy service levels improve considerably; access to basic power consumption services is easily available and the gap in per capita residential power consumption levels between urban and rural households diminishes significantly.

The overarching target of achieving 15% non-fossil energy consumption in 2020 and 20% non-fossil energy consumption are unpackaged in a series of measures and guidelines. Additionally, minimum targets for renewable energy capacity deployment are covered in the 13th FYP for Renewable Energy. Similar targets exist for coal power deployment, and express a deployment cap, or maximum, which is not exceed in the scenarios.

Renewable energy deployment in the 13th FYP period is guided by existing targets for capacity deployment under the 13th FYP for Renewable Energy and adjusted based on the *Guiding Opinions on the implementation of the renewable energy 13th FYP (NEA Doc 31, 2017)*. These guiding opinions are the expression of the National Energy Administration's approval of provincial plans for renewable capacity development for wind, solar, biomass, and municipal solid waste. The guiding opinions have been analysed in relation to current renewable energy capacity development to reach the revised targets used in both scenarios as minimum provincial capacity development targets until 2020. It is important to note that these targets have been increased in the guideline document relative to the original publication of the national energy FYP, and the FYP for renewable energy. This is due to the continued rapid development of new renewable energy capacity in 2017, most notably, the 13thFYP2020 target for solar is likely to be achieved in 2017. The revised targets add up to 134 GW more renewable energy capacity than the set 13th FYP targets.

Table 8-5 13th FYP 2020 renewable energy targets and 2020 targets used in both scenarios.

National capacity targets	13th FYP 2020 target	Scenario 2020 target
Power generation	**676 GW**	**809 GW**
Hydropower	**340 GW**	*Unchanged*
Wind	**210 GW**	**259 GW**
• Onshore	205 GW	*Unchanged*
• Offshore	5 GW	*Unchanged*
Solar	**110 GW**	**187 GW**
• Utility PV		115 GW
• DGPV		66 GW
• CSP	5 GW	*Unchanged*
Bio	**15 GW**	**24 GW**
• Biomass	7 GW	13 GW
• MSW	7.5 GW	10 GW
• Biogas	0.5 GW	*Unchanged*
Other renewable energy	**0.55 GW**	*Unchanged*
• Geothermal	0.5 GW	
• Ocean	0.05 GW	
Biogas (produced)	**8 billion m^3**	*unchanged*
Heat supply	**151 Mtce**	*unchanged*
Solar water heating	96 Mtce	
Geothermal heating	40 Mtce	
Heating from biomass	15 Mtce	

The 13th FYP for electricity also includes a target to retrofit 220 GW of coal power capacity for flexibility. This is not implemented as an explicit target but the modelling, results exceed this non-the-less. The retrofit of coal power plants is discussed more extensively in Part 3 of this report.

Medium and long-term

Renewable energy shares

After 2020 we move away from technology based capacity targets to share of power generation. The model deploys the suitable renewable energy technologies to satisfy the set share of renewable energy in the system. These shares differ in the two scenarios.

For each of the two scenarios there is an overall renewable energy share as well as resource specific energy shares as targets. Adding to this there are still a few capacity targets to push development for offshore wind, solar PV, biomass power, ocean energy and geothermal power capacity.

Table 8-6 Minimum RE portfolio modelling requirements

	Stated Policies		**Below 2°C**	
	2030	**2050**	**2030**	**2050**
Wind	11%	16%	15%	22%
Solar	7%	10%	11%	15%
Bio	1%	2%	1%	2%
RE (incl. hydro)	39%	47%	46%	58%

The minimum RE portfolio targets are exceeded in both scenarios resulting from the demand for reduced carbon emissions and technological progress driving up the competitiveness of renewable energies.

Table 8-7 Resulting RE share of power generation

	2016	**2020**	**2030**	**2040**	**2050**
Stated Policies	16%	33%	51%	65%	78%
Below 2°C	16%	45%	68%	80%	85%

Technology specific targets for renewable energy technologies

Wind

The 13th FYP stipulates 5 GW offshore wind capacity to be under construction in 2020. This is the basis for a total target of 10GW installed in 2022. The provincial distribution of these installations is based on provincial plans.

Solar

In both scenarios, there is a 137 GW utility scale PV capacity target for 2030. In the Below 2°C scenario there are additional mid and long-term capacity target in place for solar power.

In 2030 solar capacity is set to reach 1,000 GW and 2,200 GW by 2050 at national level in the Below 2°C scenario.

Bio

Total bioenergy capacity is set to reach 28.9 GW in 2030, this is the same for both scenarios and made up of 14.6 GW straw and wood, 13.7 GW municipal solid waste, and 593 MW biogas capacity.

Ocean and geothermal

As ocean power is not fully commercialized its future application is uncertain. The short-term target in the 13th FYP is followed by a 0.5 GW target in 2030 and then 50 GW in 2050. This is true for both scenarios. Geothermal energy is assumed to expand after 2030 and reach 20 GW in 2050 in both scenarios.

8.4 Resource constraints

The power sector development is also constrained by the economic efficiency of available resources. Therefore, the scenarios are subject to specific development limitations on the deployment of:

- Wind power
- Solar power
- Biomass
- Ocean energy
- Hydropower
- Pumped storage
- Nuclear power

The detailed foundation of the renewable energy limitations are presented in further detail in Chapter 13 in their respective sections, including how the resources are attributed at a provincial level. Methodologically, the resource constraints are implemented as follows.

Wind power

Onshore wind is represented at a regional level. For each of the 32 regions a maximum installable capacity is provided. This regional potential is further subdivided into three tiers of resource quality, characterised by the average wind speed of the time series in that region and tier. Finally, each resource tier is subdivided into four cost tiers, modifying the technology specific investment cost of each wind turbine technology deployed in that tier. These cost modifiers represent an aggregated assessment of the proportion of wind which can be developed in each region; for example, at the lowest cost on flat terrain, with good access infrastructure and low grid access costs, conversely at highest cost in mountainous terrain with no access roads and costly grid connection. This effectively creates 384 distinct resource classes for onshore wind power with respect to location, cost and quality. Furthermore, different wind power technologies can be installed in each of these areas.

Offshore wind is treated separately and limited to 10 coastal provinces, in areas with low water depth, and while taking into account considering exclusion zones. Four cost tiers subdivide the potential. These reflect the diversity offshore site development costs such as distance from land and water depth, among others. These lead us to impose 40 district resource limitations on offshore wind.

Solar power

Solar power resources are also limited in each of the 32 regions. Each region's potential is subdivided into distributed PV related to buildings, other distributed PV, utility scale PV and concentrating solar power. Each of these four categories are subdivided by four cost tiers, creating a total of 512 distinct resource limitations covering location, technology, and cost.

Bioenergy

Bioenergy resources are defined by an annual available energy quantity in each of the 32 regions. Hence contrary to wind and solar, bio energy is not limited in terms of MWs but in terms of GJs. The bioenergy resources cover biogas, municipal solid waste, solid biomass consisting of stem and stalk materials (straw), and biomass consisting of more bulky materials such as wood and wood waste. Biomass available for the energy system depends on the supply chain, which must be developed. Therefore, the resource potential of each bio energy type increases as action is taken to improve the supply chain, such as the implementation of collection systems, and improved forestry practices.

Ocean energy

Ocean energy potential is considered to be rather limited in China. Total ocean energy potential includes different technologies such as wave power and tidal power. Naturally, ocean energy deployment is limited to coastal provinces, and the model representation is rudimentary. Assumptions are identical for both scenarios.

Hydropower

Hydropower development is fixed by exogenous scenario assumptions and is identical in the two scenarios.

Pumped storage

Pumped storage is one of several ways to establish electricity storage, but its development is constrained by a maximum installable capacity potential in each of the 32 regions. The total potential is 238 GW.

Nuclear power

Like hydropower, nuclear power is fixed exogenously by scenario assumption and the level of deployment is the same in both scenarios. In both scenarios, due to safety and site selection limitations, nuclear power installed capacity will be mainly located in coastal regions. Nuclear power will be primarily used to satisfy base-load demand of the eastern region. Hence, the scale of installed capacity under the said two scenarios will not be any different. By 2020, China will complete 58 GW of nuclear power generation capacity as per the 13th FYP target. In 2030 generation capacity reaches 70 GW. With improved safety and better performance of nuclear power, installed nuclear power generation capacity reaches 120 GW by 2050.

Table 8-8 Available/utilised resources of main non-fossil generation sources in 2020 and 2050.

Available resources	2020	2050	Note
Hydropower	**341 GW**	**529 GW**	*Assumed installation*
Wind	**5,117 GW**		*Available to power sector*
• Onshore	4,900 GW		
• Offshore	217 GW		
Solar	**3,757 GW**		*Available to power sector*
• Utility PV	2,537 GW		
• DGPV	912 GW		
• CSP	308 GW		
Bio	**5,514 PJ**	**8,295 PJ**	*Available to power and DH sector*
• Biomass	1,348 PJ	2,022 PJ	
• MSW	1,314 PJ	1,995 PJ	
• Biogas	2,852 PJ	4,278 PJ	
Nuclear	**58 GW**	**120 GW**	*Assumed installation*

8.5 Power market reform

The ongoing process of power sector reform is assumed to have rather successful implementation in both scenarios, with identical assumptions as follows.

In both scenarios, the implementation of market reform is essentially about removing constraints, which are put on the model in the initial stage. From a modelling perspective, perfect competition is the default behaviour of a cost-minimization model. Market prices are calculated for each hour or time step as the equilibrium between supply offers and demand bids, and the price is set in equilibrium. This is congruent with competitive behaviour, and through analysis of these shadow prices, the inherent properties of a well-functioning market can be verified. For example, through cost-optimal generation and consumption, and optimal investments in new capacity on the basis market prices. Excessive profit-making is limited ensured through the free entry and exit of the market.

The initial stage of 'flawing' the perfect model is introduced in the scenario modelling by a set of constraints, which aim to restrict the power system to operate according to the current paradigm. These constraints relate to four aspects of the current power sector framework, which create an impediment to efficient outcomes, but whose effects is assumed to gradually be reduced as power sector reform gradually reorganises the power sectors regulatory framework.

The elements included to represent the lack marketisation are the following:

- 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 – according to the predominant current practice of operating interprovincial interconnections, simple flow schedules are adopted where the flow from one province to another is kept at a constant level during the day and a different constant level during the night.

Furthermore, technology options are excluded prior to the existence of market signals.

- Technologies for the consumption of electricity at times when the system value, and thereby market price, is depressed due to oversupply, such as electricity consumption in the district heating sector.
- The above also applies to releasing the demand side flexibility such as reducing air conditioner loads in buildings when the price in a market would be high, or shifting of industrial process demand.
- Smart charging of electric vehicles requires a market based incentive to use power with the system marginal costs are low.

Generation rights

As specific data on the generation rights allocation is not available, the 2016 full load hours of thermal power generators in each province is taken as a proxy, and implemented as a requirement. As the market reforms are assumed to progress, this minimum annual full load hour requirement is reduced linearly from the 2016 starting point, to zero in 2025.

While the concept of generation rights in the Chinese power system is already being changed, the replacement is bilateral contracting between thermal generators and large consumers. From a power system balancing perspective, this will have a similar implication as the generation rights and therefore the digression of the annual full load hours, can alternatively be viewed as the gradual improvement necessary with a bilateral contracting structure not to lock-in the generation, with lead times ahead of wind and solar forecasts being reliable.

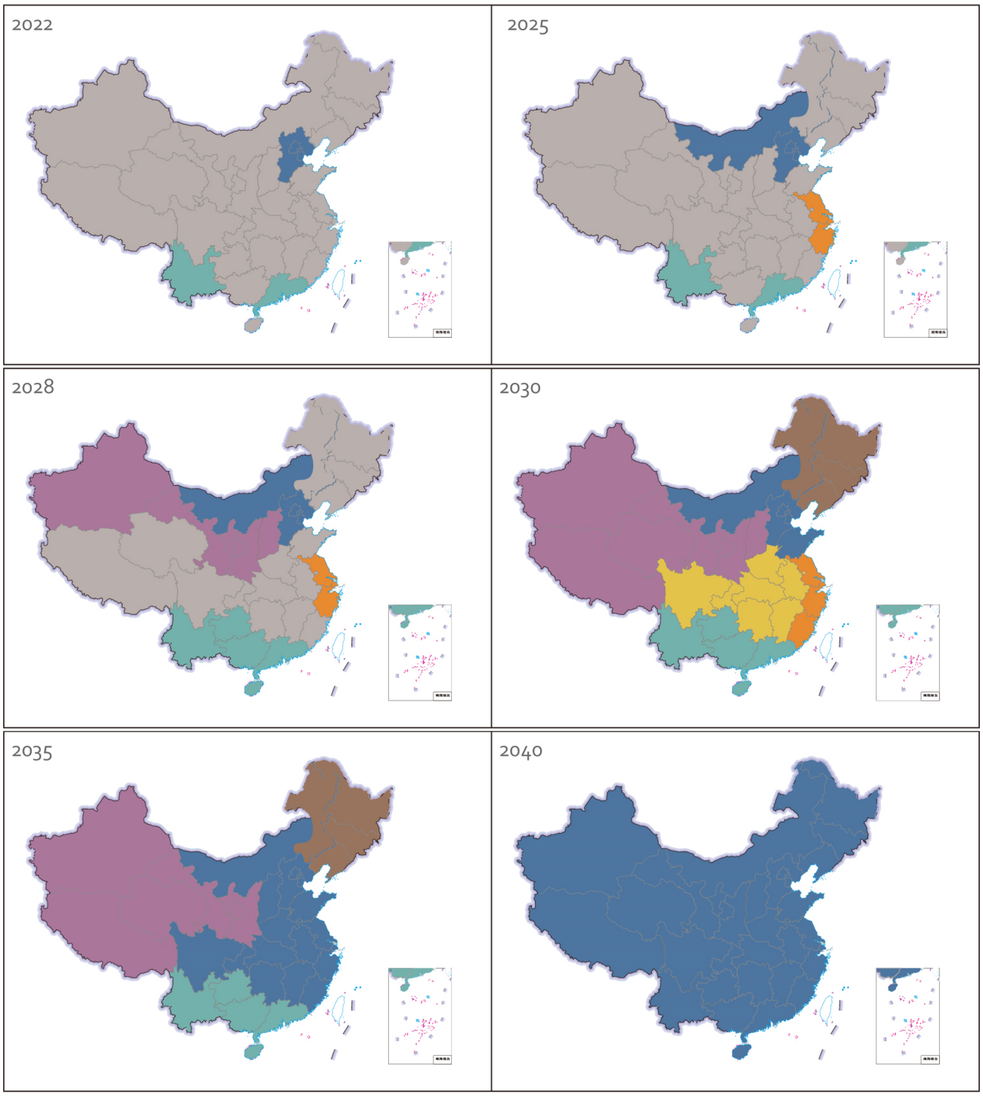
Interprovincial transmission

The lack of flexibility in the operation of interprovincial transmission is assumed to be relaxed over time. This far, market pilot programmes being rolled out in China have been focused predominantly at provincial level. It is assumed that efficient trade develops over time and that one way or another, markets will start to connect as arbitrage opportunities become apparent from increasing transparency in price setting. A gradual development towards an interconnected market is assumed. There can be no firm basis for defining which markets will integrate at which time, but despite this a development pathway for this process is assumed.

It is assumed that before 2020 the market piloting will remain provincial, and while there may be efforts to improve interprovincial trading of power, therefore interprovincial transmission flows will not be governed economically efficient factors such as hourly market prices. However, by 2022 it is assumed that the first interprovincial markets emerge and power transmission operating schemes evolve along with them.

On Figure 8-1 the evolution of combined market regions assumed in the scenarios are illustrated. The grey areas are not assumed to take part in an interprovincial spot market.

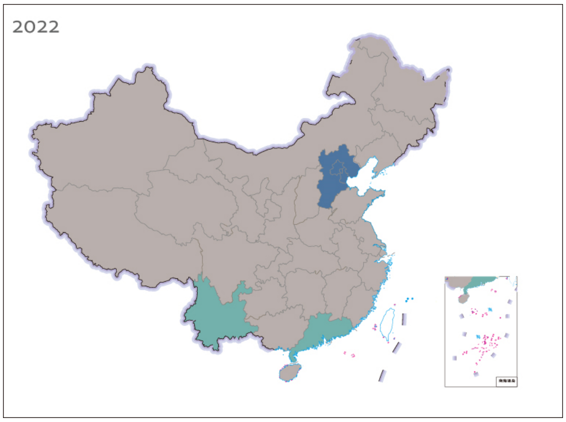
Figure 8-1 Assumed evolution of an interconnected electricity market in China



First markets connect

Based on a superficial assessment of where interprovincial cooperation may first underpin market collection, it is selected that two interprovincial markets shall be started by 2022. The broader capital region of China, Beijing, Tianjin, and Hebei province, where a Jing-Jing-Ji spot market has been debated and grid operation for Beijing-Tianjin and northern-Hebei is under a common umbrella (Jing-Jin-Tang) and there is significant and complex trading already within the region. Therefore, the Jing-Jin-Ji region is assumed to be an early mover (shown in blue in year 2022).

Figure 1-2 The first interprovincial markets in the capital region and Yunnan-Guangdong

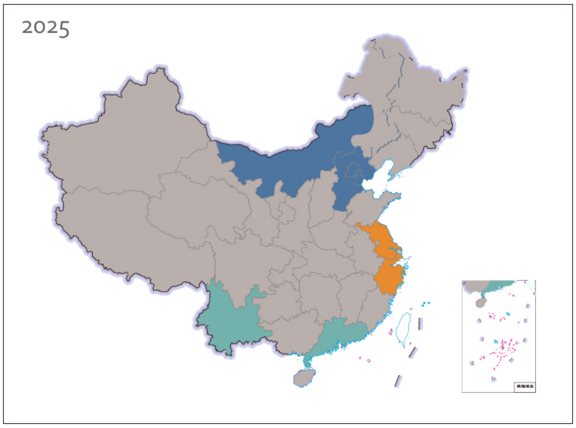


Meanwhile, the hydropower rich Yunnan province and the industrial powerhouse of Guangdong are also assumed to connect markets in 2022 with existing West-to-East Transmission HVDC infrastructure as a physical tie. Both provinces are progressive in terms of promoting power market reform and are starting to implement some form of day-ahead trading. Meanwhile a significant proportion of Yunnan's hydropower is exported to Guangdong via long-distance transmission. These are shown in green in Figure 1-2.

Second stage of connection

By 2025 the Western Inner Mongolia grid region's market is assumed to connect with the Jing-Jin-Ji regional market. Significant power flows from Western Inner Mongolia and the potential integration benefits of connecting this wind power intensive region with the large Jing-Jin-Ji load centre could make this connection a priority.

Figure 8-3 Western Inner Mongolia Connects to the capital region and a trading hub is formed in the Yangtze River Delta



Meanwhile, Jiangsu, Zhejiang and Shanghai in the Yangtze River delta form a common trading hub (shown in orange in Figure 8-3).

Regional grids become the natural market areas

By 2028 the JJJ-West Inner Mongolia market expands to cover the entire north China grid footprint, including Shandong's provincial market (blue). In parallel, the Yunnan-Guangdong pilot market is expanded to cover all the South Grid footprint in Yunnan, Guizhou, Guangxi, Guangdong, and Hainan (green). We also see the beginning of a Northwest market in 2028 covering Xinjiang, Gansu, Ningxia and Shaanxi, but quickly expanded to include Qinghai and the Tibetan power grid in 2030. This market area is shown in purple on the 2028 and 2030 pictures. By 2030 all six grid regions have formed interconnected markets, including also East China (orange), Central China (yellow) and the Northeast power grid (brown).

Figure 8-4The capital region expands to cover the entire north China grid, the Yunnan-Guangdong market covers the south grid while the north-west market emerges.

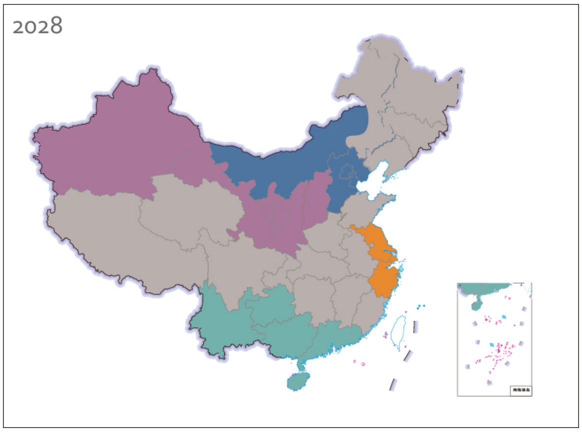
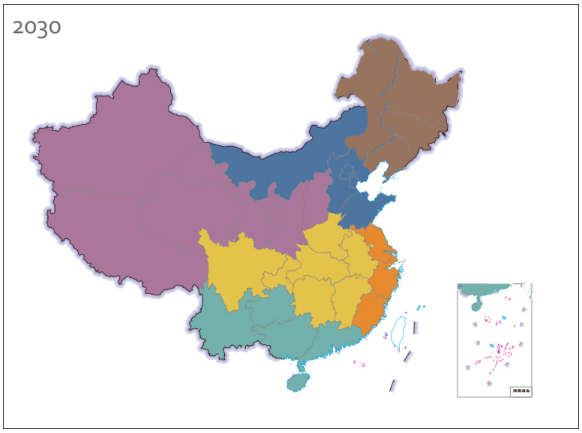


Figure 8-6 By 2030 the north-west market includes the Tibetan and Qinghai power grid. By 2030 all 6 grid regions have interconnected markets.



San Hua to a nationally integrated market

A consolidation of the interior markets in China occurs around 2035 with the so-called San Hua area arising from the integration of the North, Central and Eastern grid (blue). Finally, by 2040 it is assumed that all mainland Chinese markets are integrated and the market have full reign of short-term supply demand balancing and pricing.

Obviously, this is but one illustrative pathway that the development of a nationally integrated spot market could take from the starting point of provincial market pilots ongoing today. The pathway is common for the two core scenarios. In Part 3 of this report in the chapter dedicated to wholesale power markets, alternatives to this pathway are investigated.

Figure 8-7 By 2035 San Hua area arises from integration of the North, Central and East China grid

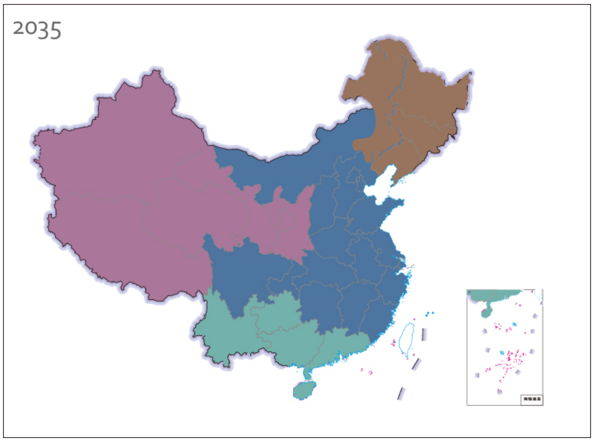
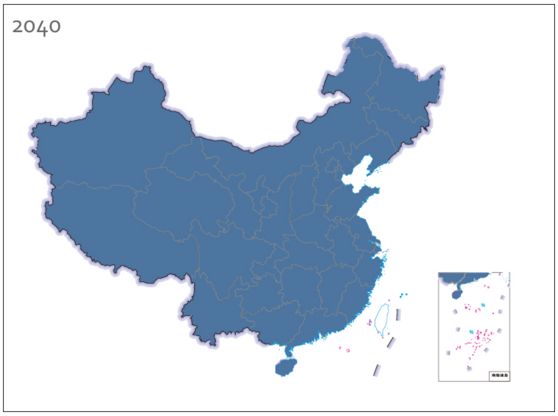


Figure 8-8 By 2040 all markets will have been integrated.



Market reform dependent technologies

The operation of a district heating technologies such as electric boilers, heat pumps and heat storage is not economically viable unless they can capture the system benefit of operating flexibly according to the needs of the power system. While pilot projects may be deployed, widespread adoptions require incentives and market signals. For this reason, their deployment in the Chinese power system is currently negligible, however, there is significant potential for using these technologies to further integrate power and district heating systems, given that the market framework allows for a positive business case. It is assumed that this possibility is available by 2020, and therefore these technologies can be installed on a least cost basis from 2020 and beyond.

Demand side response

Demand response is another potentially powerful integration option, which 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. This often involves shifting demand from high price to low price times. Utilising demand response as a flexibility option requires both physical flexibility from responsive loads, and the appropriate institutional structures 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.

Smart charging of electric vehicles

The deployment of electric vehicles creates additional load. When establishing this new infrastructure there is an opportunity, and perhaps a necessity, to ensure that this new vehicle fleet does not just charge when owners park and connect their vehicles, as this would create new serious challenges for the power system. The opportunity for making this new load 'smart' is implemented in the scenarios. The phase-in of smart charging is also a component of the power sector reform development.

The penetration of electric vehicles is highest in the Below 2°C scenario and therefore the electric vehicle charging consumption is also higher in this scenario.

It is assumed that in 2020 a negligible number of electric vehicles will have the necessary incentives and infrastructure for smart charging, but this will quickly increase such that by 2040 virtually all EV's will be exposed to market prices when charging, and therefore we anticipate will do so "intelligently".

8.6 Fuel cost development

Coal

Fuel prices for coal differ in the two scenarios. The coal price assumptions are based on 2016 market prices and the indexed development by the World Energy Outlook (WEO) 2016 coastal coal prices for China up until 2040. From 2040 to 2050 coal prices are expected to develop following the trend as between 2030 and 2040. In the Stated Policies scenario prices follow the indexed development in the WEO New Policies Scenario and for the Below 2°C scenario price development follows the WEO 450 ppm scenario. Coastal coal prices follow development from current levels and inland prices converge towards coastal prices over time to 80% convergence in 2050. The convergence is assumed as the current difference in coal prices, are higher than can perceivably be justified by the long-run cost of transport. This could be due to congestion in the rail system and other imperfections or barriers in the logistics market. In the long-run, these differences are assumed to subside. Furthermore, it is assumed that the economy which is currently skewed between the affluent coastal regions and the less affluent inland regions, will be levelled out as part of China's economic development until 2050. This implies that purchasing power, demand, wages, and commodity prices all increase faster in the inland versus the coastal regions.

Figure 8-9 Coal prices (RMB/GJ) in 2016.

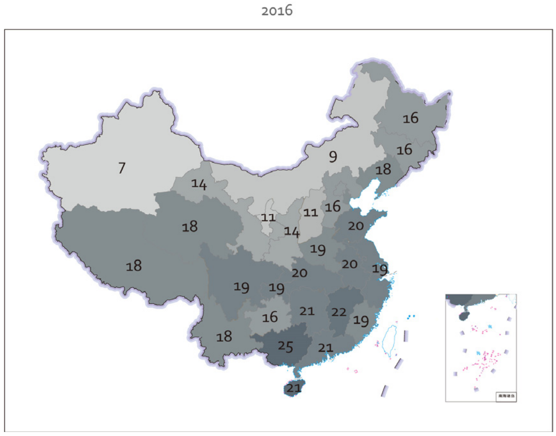
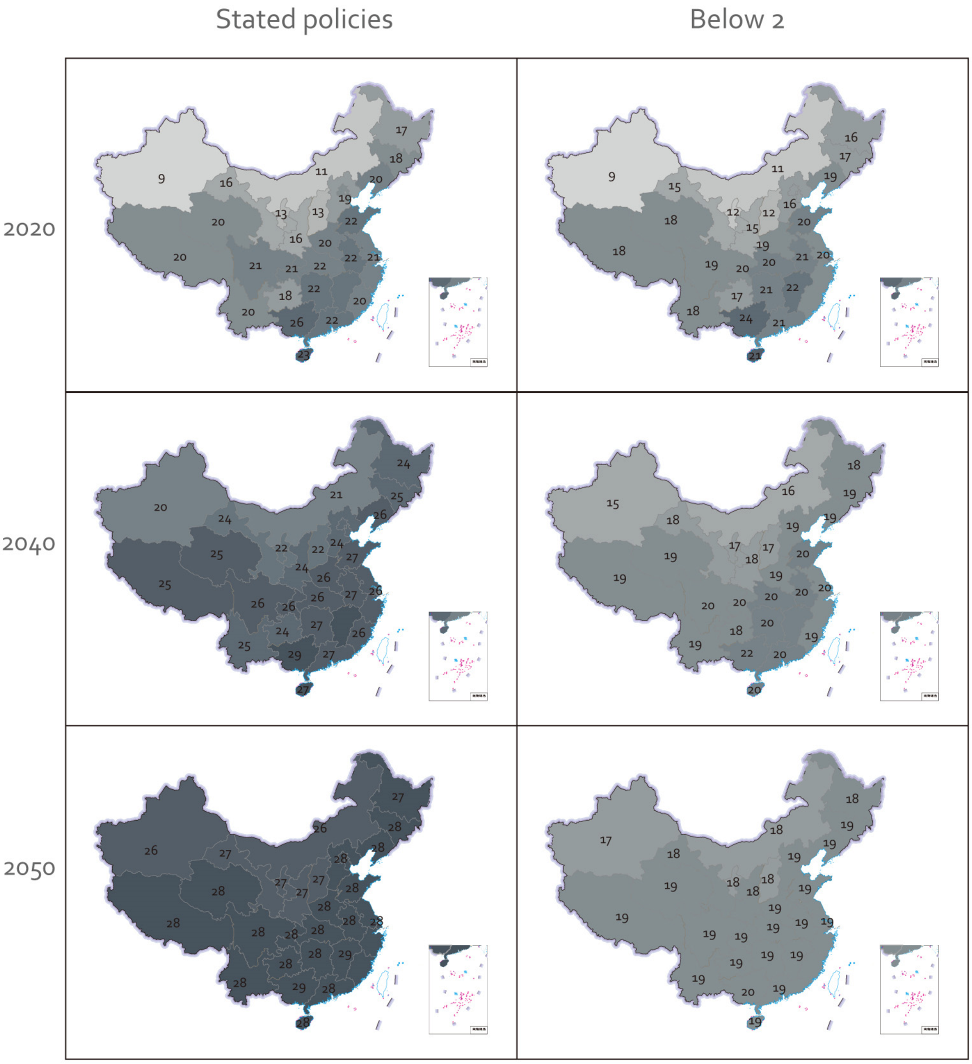


Figure 8-10 Coal price development (RMB/GJ) from 2020 to 2050 in the two scenarios.



Natural gas

Natural gas prices differ by province with a baseline price based on city gate prices, and the development indexed to the WEO prices. From 2040 to 2050 prices are expected to develop at the same level as from 2030 to 2040. Here again, the Stated Policies prices follow the WEO new policy scenario price development and the Below 2 °C scenario follows the WEO 450ppm scenario price development.

Figure 8-11 Natural gas prices in 2016 (RMB/GJ).

2016

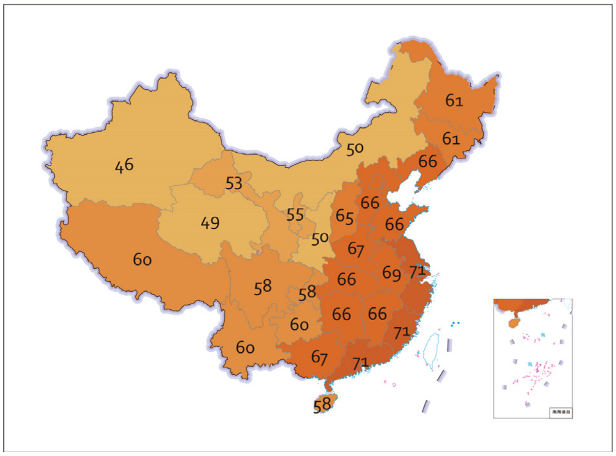
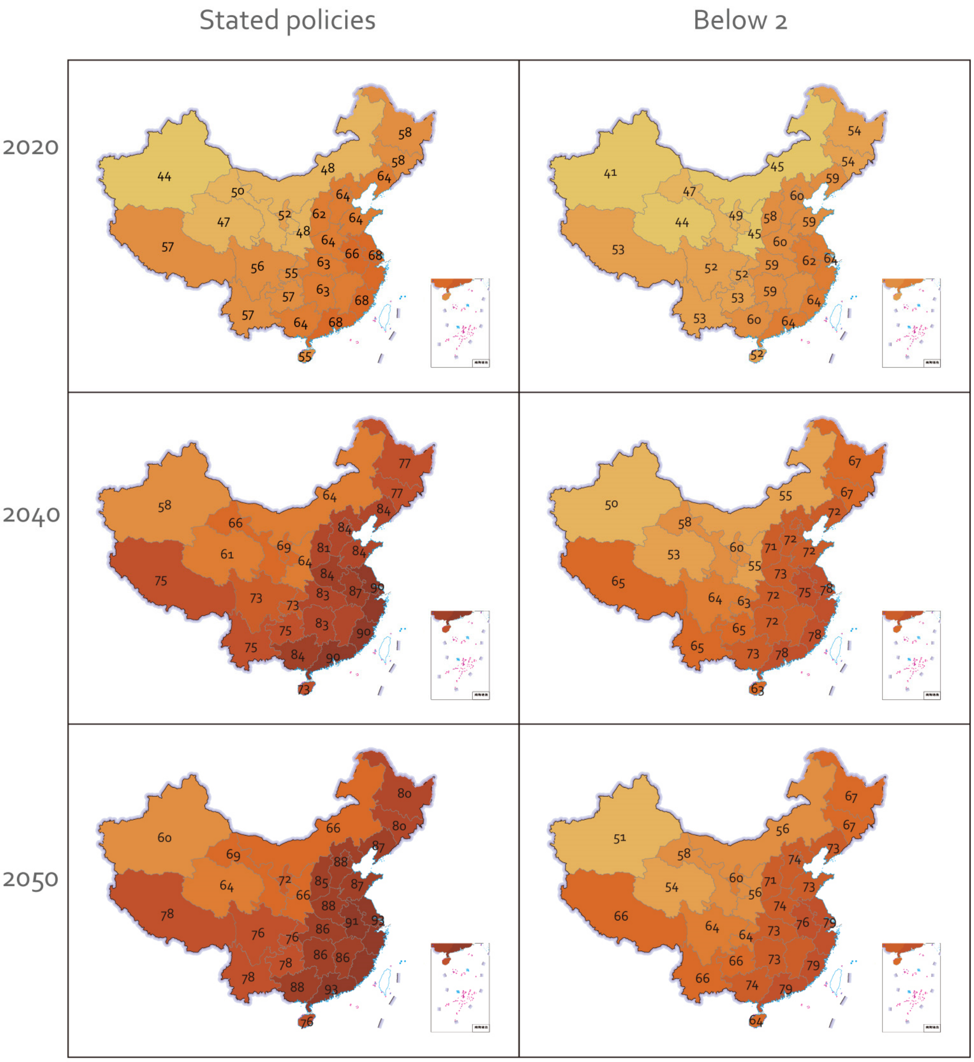


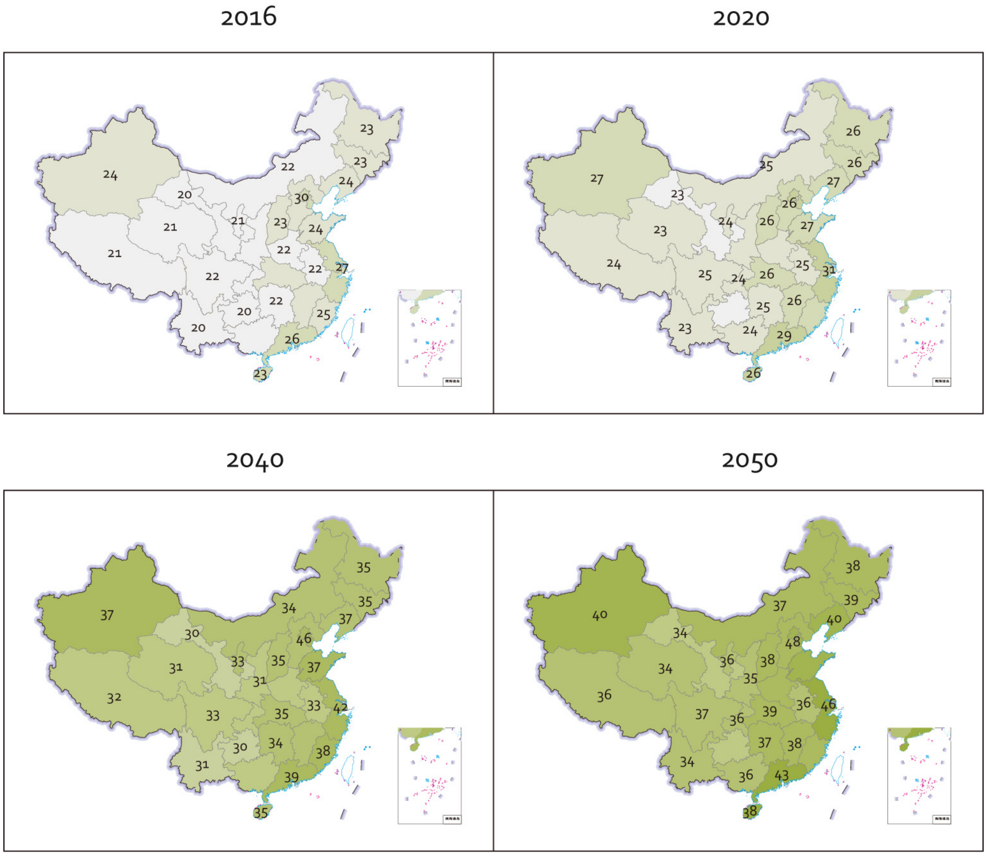
Figure 8-12 Natural gas price development from 2020 to 2050 (RMB/GJ) in the two scenarios.



Bioenergy

Bio fuel prices are based on CNREC analysis and the same prices are used for both scenarios. Straw prices differ by province while biogas and wood price details not as nuanced and therefore is assumed to be the same for the whole country.

Figure 8-13 Straw price development from 2016 to 2050 (RMB/GJ).



Unit: RMB/GJ	2016	2020	2030	2040	2050
Biogas	54	57	67	71	79
Wood	32	34	38	42	46

9 Energy system outlook

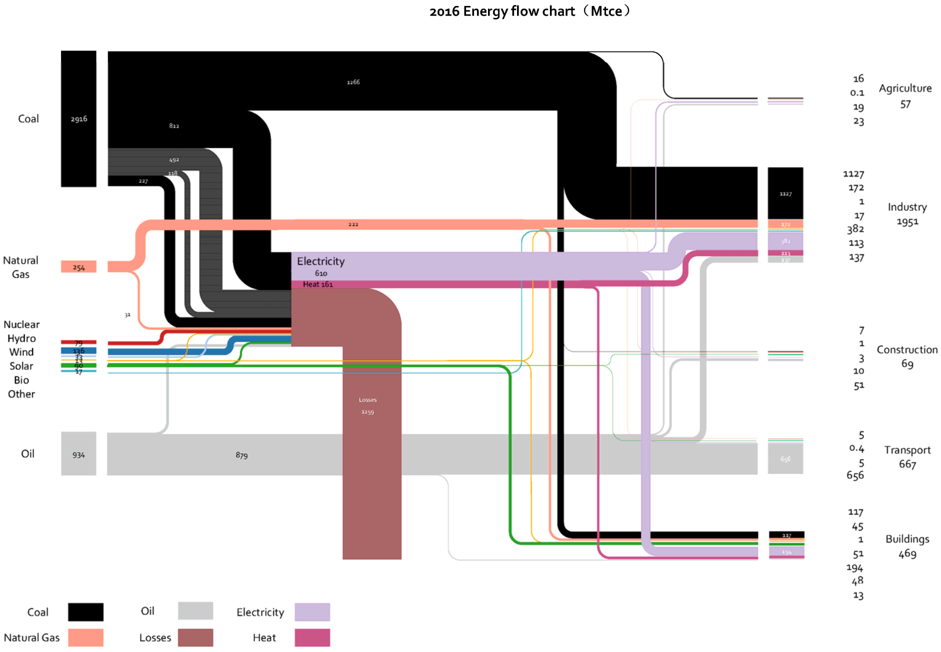
In this chapter, we will look at the results from the scenario analyses from an energy system perspective, combining the output from the different CNREC models. In the subsequent chapters the end-use sectors and the power sector will be described in more detail, as well as analyses of the macroeconomic impacts of the scenarios. These are followed by a renewable energy technology outlook and finally a fossil fuel outlook based on the two CREO scenarios.

9.1 Energy system flows

With the given drivers, targets, and assumptions for the two scenarios, as described in the previous chapters, the Chinese energy system will go through a significant transformation in the next 35 years.

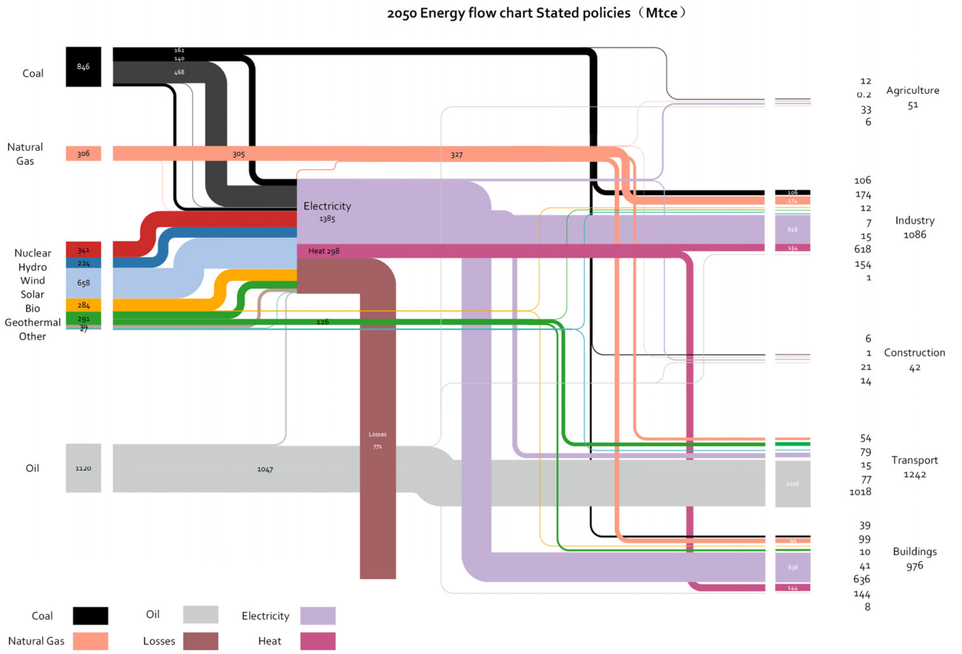
The energy flow through the Chinese energy system from fuel transformation to end-use sectors is shown in the following flow charts for 2016 and for 2050 for each of the two scenarios.

Figure 9-1 Energy flow chart for the Chinese energy system in 2016



The 2016 system is characterised by the massive consumption of coal in the power and in the industry sectors, and considerable loss of energy through the transformation of coal to electricity.

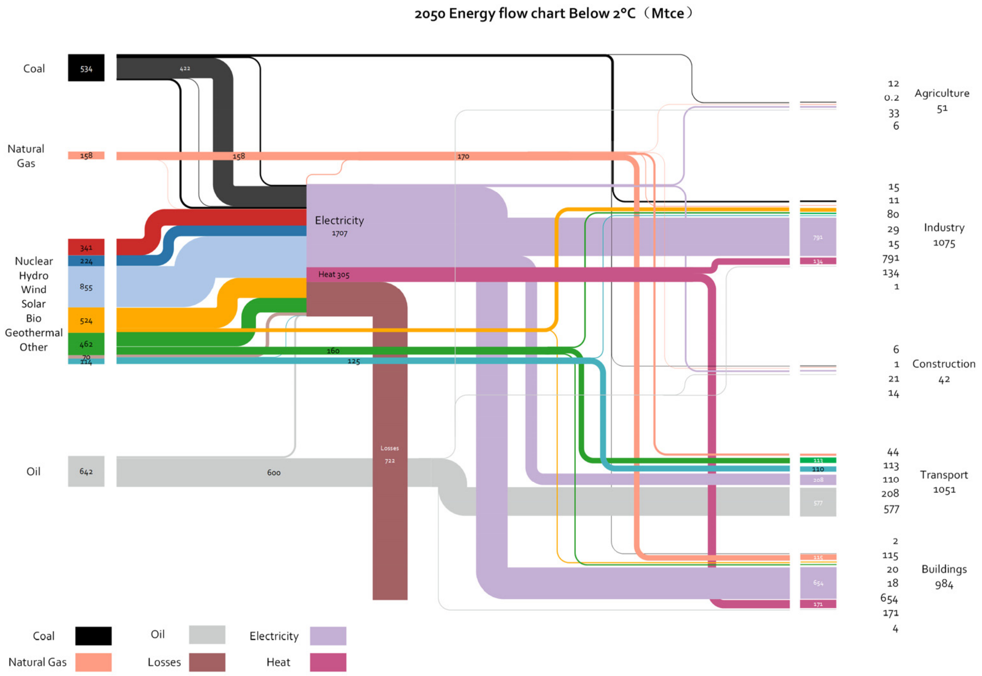
Figure 9-2 Energy flow chart for the Chinese energy system in 2050 for the Stated Policies scenario



In 2050 the fuel supply is much more diverse. Coal is drastically reduced in the end-use sectors and replaced with electricity, and the electricity and district heating is produced by a number of sources, where wind the biggest contributor. The losses in the system are reduced, mainly because wind and solar power is directly transformed from wind and solar energy to electricity, but the efficiency of the remaining thermal power plants is also increased. The transport sector is still dominated by oil as fuel in the Stated Policies scenario.

In the Below 2 °C scenario these development trends are taken even further. The electrification of the energy system is now dominant, and electricity also has a bigger share of the transport sector's energy consumption. The use of coal is diminished and renewable energy dominates in power production.

Figure 9-3 Energy flow chart for the Chinese energy system in 2050 for the Below 2 °C scenario



Energy demand

The energy demand structure will change considerably in the future. Today the industry sector is dominating energy demand. In 2050 – while the total energy demand will be at the same level as today – the composition will change. The energy consumption in the industry sector will be much lower, while the energy use in the transport and building sectors will grow.

Figure 9-4 The final energy demand (Mtce) in 2016 and in 2050 for the two scenarios, divided on main economic sectors

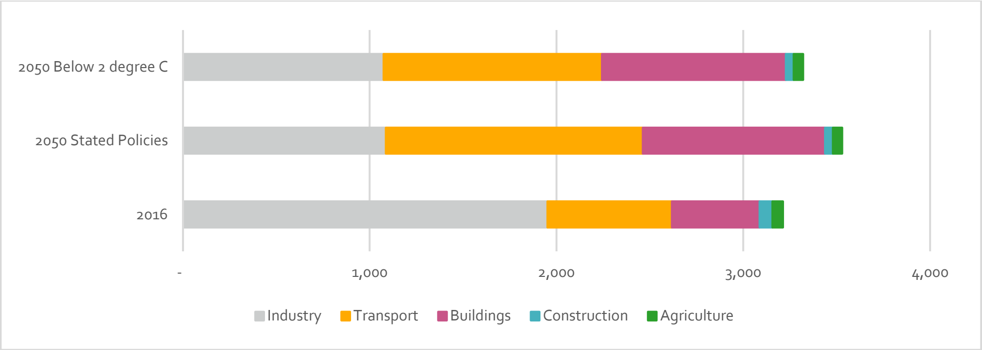
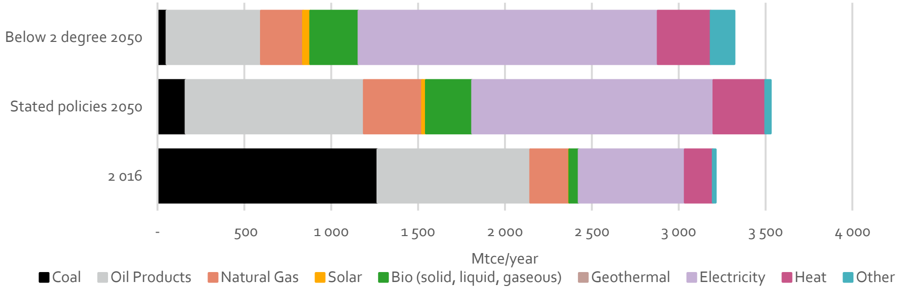


Figure 9-5 Final energy demand (Mtce) in 2016 and in 2050 for the two scenarios divided on primary and secondary fuels



The development of energy demand is characterised by a high degree of electrification and a shift to less energy-intense industry. A series of extensive energy efficiency measures are in place in both scenarios. This is the main reason the energy demand follows a similar trend in the two scenarios with a peak around 2030. In 2016 China's final energy demand was 3213 Mtce (4727 Mtce using the coal substitution method). After peaking around 2030 in both scenarios energy demand will reach 3202 Mtce in the Below 2 °C scenario and 3397 Mtce in the Stated Policies scenario in 2050.

The degree of electrification in the end-use sectors is substantial and most of this is produced from renewable sources. This is true for both scenarios, however, the electrification and share of renewable energy is higher in the Below 2 °C scenario. In the Below 2 °C scenario 52% of energy demand is electricity in 2050, compared to 39% in the Stated Policies scenario.

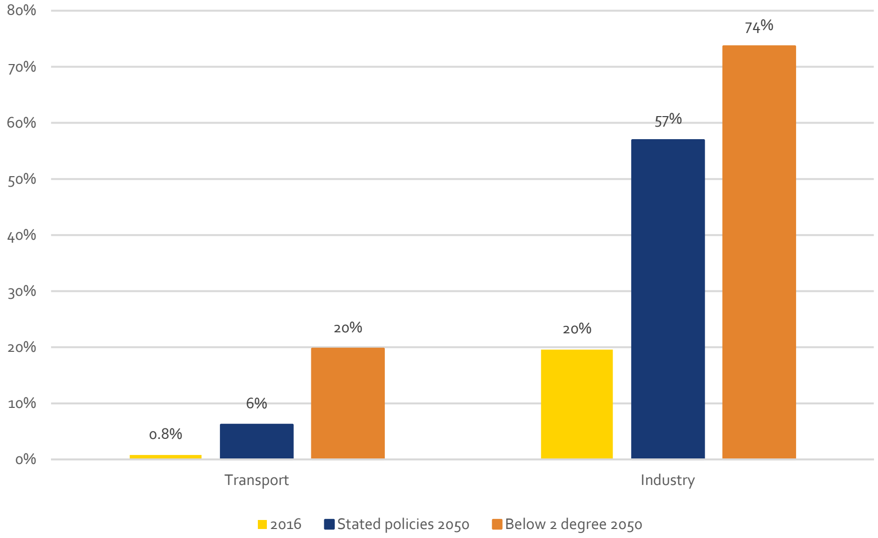
Table 9-1 Final energy demand (Mtce) in 2016 and in 2050 in the two scenarios

	2016	**2050 Stated Policies**	**2050 Below 2 °C**
Mtce/year	**3 213**	**3 397**	**3 202**
Coal	1 266	162	35
Oil Products	879	1 047	600
Natural Gas	222	327	170
Solar	2	22	100
Bio (solid, liquid, gaseous)	55	126	160
Geothermal	-	-	-
Electricity	610	1 385	1 707
Heat	161	298	305
Other	17	30	125

Electricity becomes key in transport and industry

The use of fossil energy in the industry and transport sectors will largely be replaced by electricity. Electricity used in industry will change from 20% of energy consumption in 2016 to 74% in 2050 in the Below 2 °C scenario where electricity also is used efficiently in the transport sector. China has put extensive policies in place to boost EV development. Prioritizing the EV industry will foster battery development and electricity used in transport will increased from 0.8% in 2016 to 19% in 2050 in the Below 2 °C scenario. In the Stated Policies scenario, the electrification rate is lower. Here the electrification rate of the industrial sector is 57% and for transport it is 5.9% in 2050.

Figure 9-6 Electrification of transport and industry sectors in 2016 compared to the two scenarios in 2050.



Energy supply

While the final energy consumption is slightly higher in 2050 than in 2016 in both scenarios, the primary energy consumption is lower due to a combination of electrification of the end-use sectors and much more renewable energy in the power sector. The primary energy consumption peaks in both scenarios around 2035.

The share of non-fossil fuels in the primary energy consumption is increased in both scenarios. In the Below 2 °C scenario non-fossil energy makes up 63% of energy supply in 2050, compared to 44% in the Stated Policies scenario (using the coal substitution method non-fossil energy makes up 77% of supply in the Below 2 °C scenario and 61% in the Stated Policies scenario).

Figure 9-7 The development of the primary energy supply (Mtce) in the two scenarios

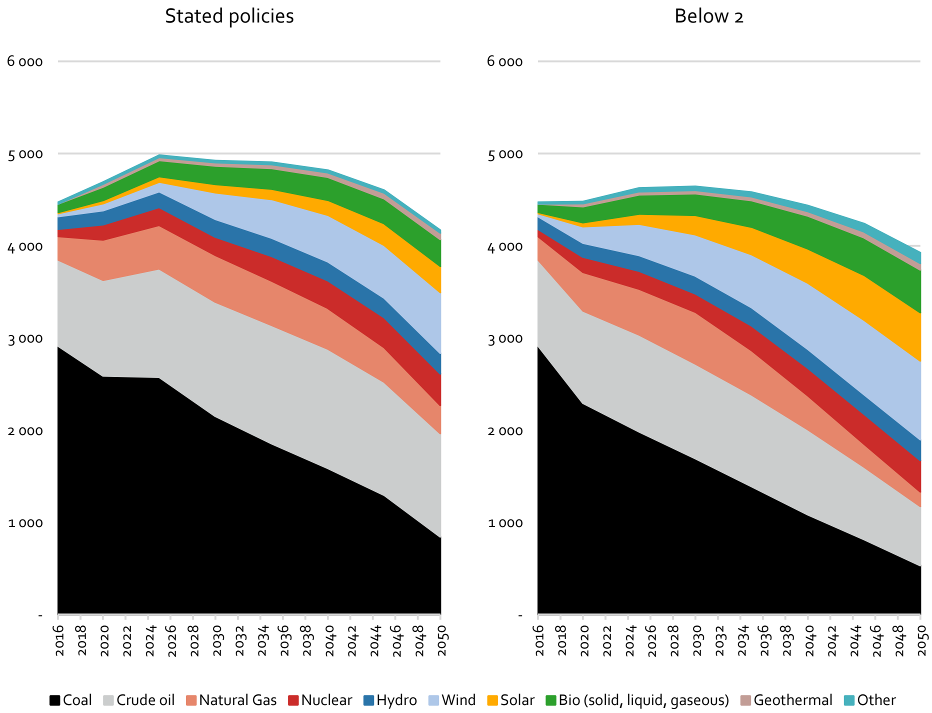


Table 9-2 The primary energy supply (Mtce) in 2016 and in 2050 in the two scenarios

	2016	2050 Stated Policies	2050 Below 2 °C
Mtce/year	**4 471**	**4 168**	**3 924**
Coal	2 915	846	534
Crude oil	934	1 120	642
Natural Gas	254	306	158
Nuclear	79	341	341
Hydro	136	224	224
Wind	33	658	855
Solar	13	284	524
Bio (solid, liquid, gaseous)	90	291	462
Geothermal	-	70	70
Other	17	27	114

The energy intensity of the Chinese economy will be drastically reduced in both scenarios. In the short-term the 13th FYP target for reductions of energy consumption by unit of GDP is overachieved in both scenarios. In the Stated Policies scenario energy intensity is reduced by 25% compared to 2015 levels and in the Below 2 °C scenario this is 32% over the five-year period. All fossil fuels make up a smaller part of the energy mix in the Below 2 °C scenario compared to the Stated Policies scenario, but the most drastic change is in coal. In the Stated Policies scenario coal make up 20% of energy supply in 2050 compared to 14% in the Below 2 °C scenario. Natural gas demand peaks in 2030 in both scenarios and oil demand peaks in 2025 in the Below 2 °C scenario and in 2039 in the Stated Policies scenario.

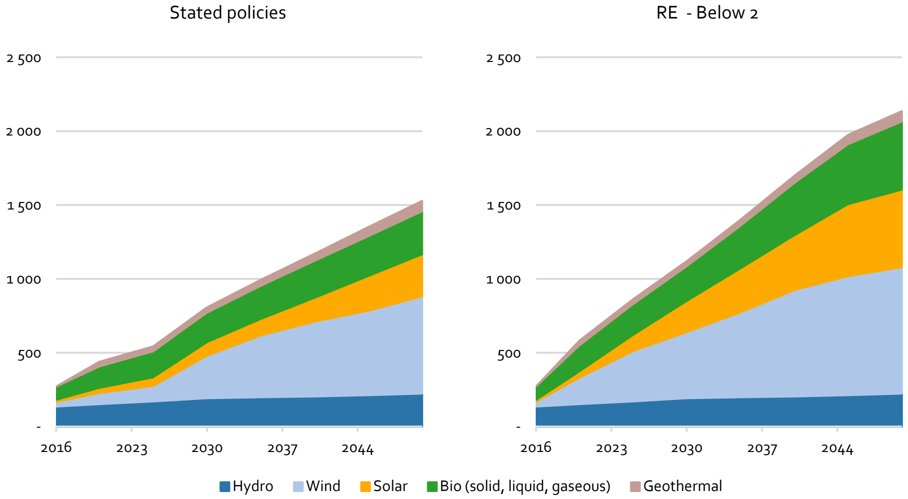
Renewable energy

By 2016, the share of renewable in total energy supply reached 6%. China will maintain its position as the world's largest investor in renewable energy the share of renewable energy will grow immensely in the coming decades following China's ambitious renewable energy policies and the need to decarbonise the energy system.

In the Below 2 °C scenario China's energy sector reforms ensure that renewable energy covers 54% of total energy supply in 2050, compared to 36% in the Stated Policies scenario (using the coal substitution method this is 72% in the Below 2 °C scenario and 55% in the Stated Policies scenario). These high renewable energy rates are made possible through a range of reforms changing the way energy is produced and consumed based on core principles of making the energy system clean, efficient, and reliable.

In 2016 renewable energy constituted 270 Mtce. Towards 2050 this increases eightfold in the Below 2°C scenario, where renewable energy amounts to 2,148 Mtce compared to an increase to 1,540 Mtce in the Stated Policies scenario. The major trend in the Below 2°C scenario is an initial expansion of wind power, followed by solar energy in the medium-term towards 2035. In the long-term towards 2050 solar energy expands and utilisation of bioenergy develops rapidly and in the Below 2°C scenario renewable energy covers most of energy demand in 2050. As there is limited potential for further development of hydro resources, these follow the same incremental growth in both scenarios.

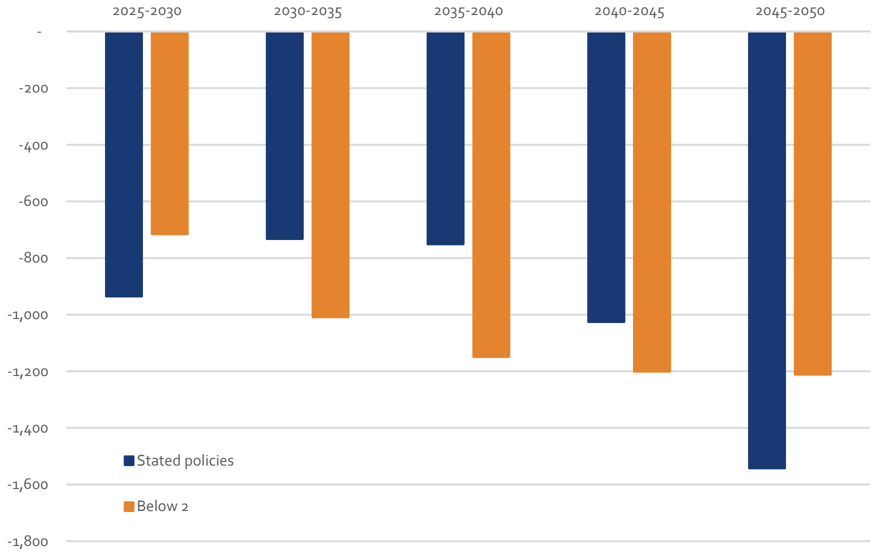
Figure 9-8 Development of main renewable energy in energy supply (Mtce) from 2016 to 2050 in the two scenarios



9.2 CO_2 emissions from the energy sector

The reduction of fossil fuel consumption will successfully set the energy sector on a decarbonisation path. Swift short-term actions lead to initial CO_2 reductions in the Below 2 °C scenario where emissions from the energy sector already have peaked. After initial reductions in the Stated Polices Scenario carbon emissions will increase slightly and peak in 2025. After 2025 the pace of CO_2 reductions is comparable in the two scenarios with average annual reductions of 200Mton in the Stated Policies scenario and 212Mton in the Below 2 °C scenario over a 25-year period.

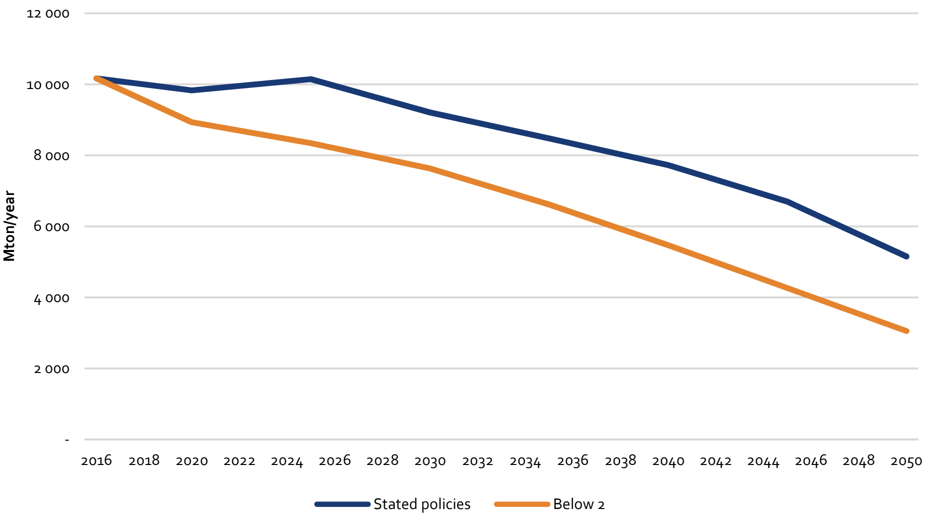
Figure 9-9 CO_2 reduction in the two scenarios compared to the previous five-year period



In the Below 2 °C scenario initial ambitious actions and subsequent steady reductions provide steady long-term reductions with extensive societal benefits. This shows the importance of swift action to reach the carbon target. In the Stated Policies scenario, the market will provide necessary push for carbon reductions in form of CO_2 pricing and cost completive renewables in the long term, but on short-term basis more ambitious policies are needed for China to comply with the Paris agreement targets. In the Below 2 °C scenario, which has the highest level of CO_2 emission reductions, the power sector will perform the most substantial reductions.

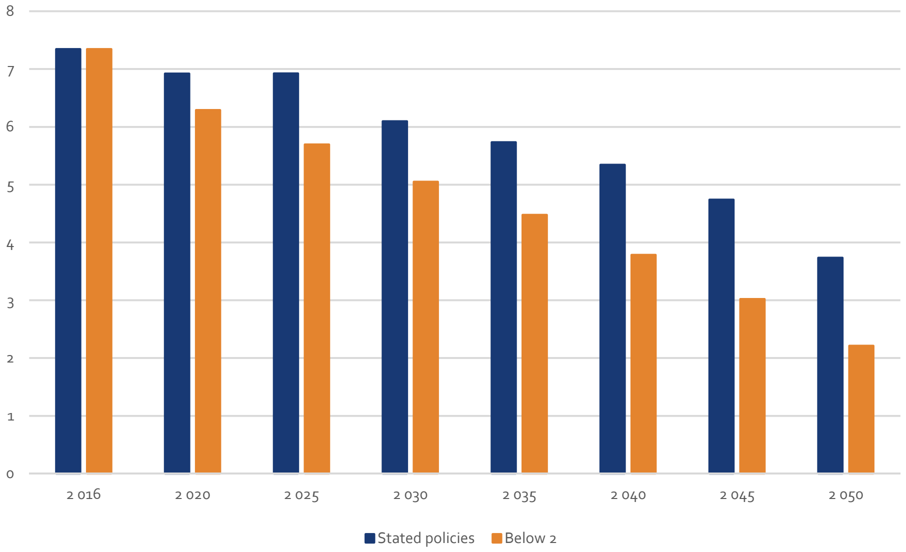
Total CO_2 emissions from the energy sector are reduced by 24% in the Below 2 °C scenario 52% in the Stated Policies scenario from 2016 levels to 2050. These reductions will contribute immensely to China reaching its 2030 target for CO2 reductions as stated in the China NDC, 60-65% reduction by compared to 2005. Solely looking at the CO2 emissions from the energy sector compared to assumed GDP development means that the 60-65% reduction will be achieved by 2025 in the Stated Policies scenario and a couple of years earlier in the Below 2 °C scenario.

Figure 9-10 CO$_2$ emissions development from 2016 to 2060 in the two scenarios.



As population development is the same in the two scenarios the per capita CO$_2$ emissions follow the same trend.

Figure 9-11 CO$_2$ emissions per capita from 2016 to 2050 for selected years in the two scenarios.



CO_2-emissions from the power sector

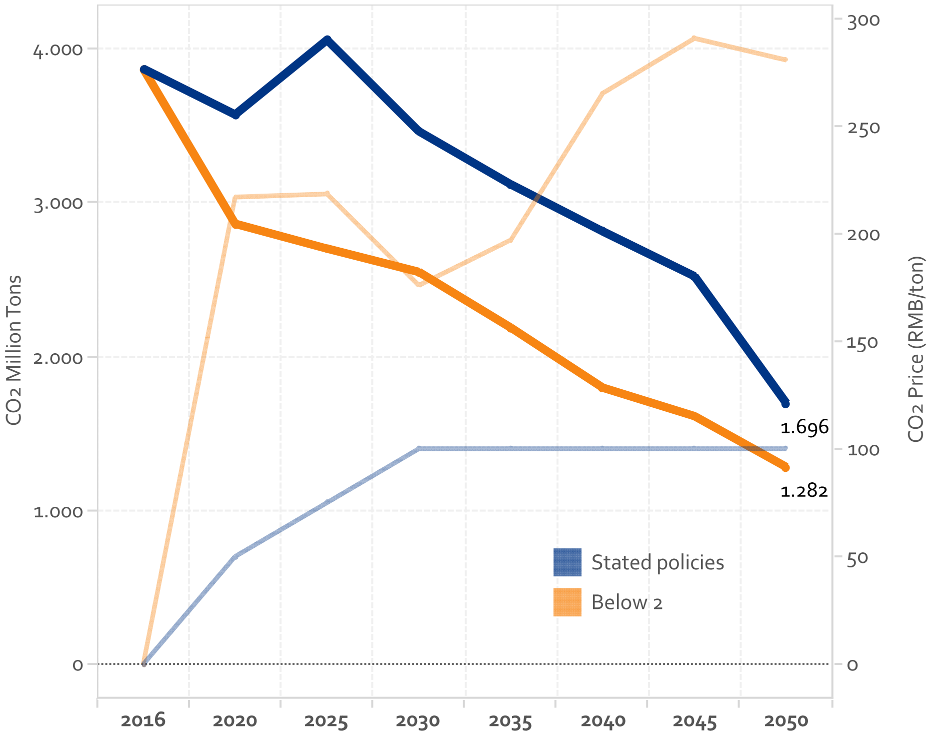
The power sector currently accounts for about 40% of China's carbon emissions. In the Stated Policies scenario, this declines to 33% of total emissions by 2050, whereas in the Below 2 °C scenario the emissions level remains at about 40%.

CO_2-emissions from the power sector are not explicitly limited in the Stated Policies scenario, but in combination with the emissions outside of the power and district heating sectors the emission level is well-below the present carbon budget for the energy system as a whole. In the power sector, emissions decline from a level of 3.9 Gt in 2016 to reach 1.9 Gt by 2050.

This decarbonisation is driven by a number of factors previously introduced, including the short-term targets and the medium and long-term scenario guidance targets for renewable electricity deployment. Secondly, the assumed successful establishment of an emission trading system which sets a market price for the emission of CO_2. In effect, this works as an incentive not to emit CO_2. In conjunction with the cost reduction of renewable energy technologies and storage technologies, the core renewable technologies are competitive on market terms with coal fired generation as long as the CO_2-price of 100 RMB/ton is realised.

Notably, the renewable energy targets and measures in the Stated Policies scenario result in a sharp decrease in power sector emissions by 2020, which implies that the short-term policies and trends are on track for starting an energy transition. However, since only very limited targets are set for 2025, the power sector CO_2-emissions climb again and peak in the middle of the decade. After 2025, the CO_2 price is expected to increase and cost-reductions for new renewable energy installations take effect to drive the CO_2 reductions through renewable energy being competitive with coal.

Figure 9-12 CO_2 emissions (million tons) from the power and district-heating sector from 2016 to 2050 (bold lines), and the modelled marginal cost of CO_2 emissions in the power sector (thin lines)



The Below 2 °C scenario's CO_2-emissions follows the pathway of the CO_2 cap provided as input. Notably, this involves a sharp drop by 2020, which results in additional renewable energy being deployed going above the given targets, particularly wind power. In the modelling sense, this development is driven by the CO_2 cap, this reveals a shadow price indicating, provided that other conditions remain the same, what the CO_2 market price should be in 2020 to drive that development. In practice, given the short-term nature of this development, raising targets using the established methods for simulating renewable energy and work for a strong and efficient carbon market to gradually take on an increasing role in driving the transition, would require strengthened political commitment. In 2030 and 2035, the modelled shadow price approaches the minimum CO_2 price set for the Below 2 °C scenario, but in the long-term the price increases to a level of 250-300 RMB. The strict targets for CO_2 abatement in the Below 2 °C scenario means that low cost options for CO_2 reduction are gradually exhausted. This drives up the marginal cost for CO_2 reductions in the power and district heating sectors.

9.3 Impacts of air pollution

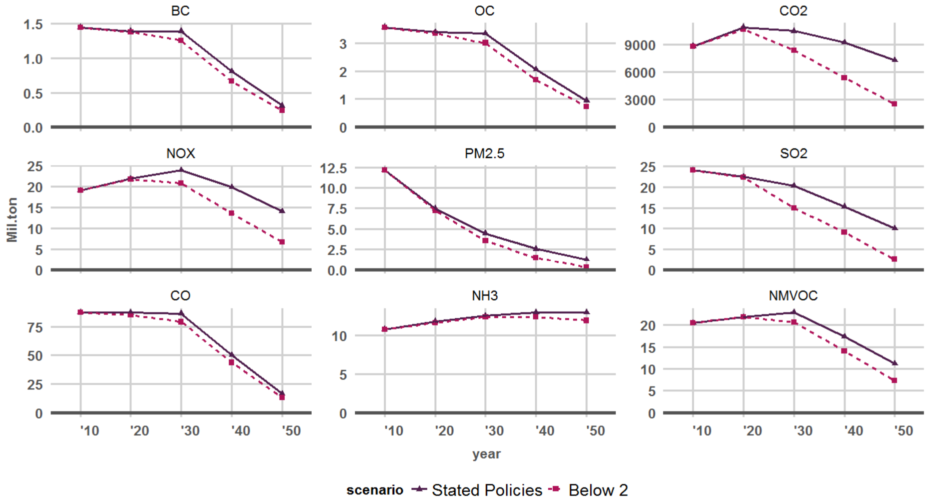
With the rapid economic development, China has become both the biggest energy consumer and air pollutants emitting country in the world. Air pollution has become a critical issue in China especially after 2010. The Chinese Government has launched a series of air pollution control policies to improve air quality and public health. Developing clean energy is an important strategy to reduce air pollutant emissions. Large scale renewable energy development will have a significant impact on the future air quality. In this section, we analyse the how the Stated Polices scenario and the Below 2 °C scenario impact air-quality and public health. The calculations are made as input to the CREO 2017 based on the two main scenarios. They are further detailed in the publication "The health impacts of developing renewable energy in China", Hancheng Dai; Yanxu Zhang, Yang Xie, and Xuanming Su, August 2017.

Emissions of pollutants and concentrations of pollutants

Figure 9-13 shows the air pollutants in the Stated Polices scenario and the Below 2 °C scenario from 2010 to 2050. Most of the pollutants have been decreasing since 2010, because of the intensive air pollution control in China. However Black Carbon, Organic Carbon and NO_x firstly increase and start decreasing in 2020. NH3 emissions are quite similar in both scenarios and decrease quickly over the whole period.

Due to the higher usage of renewable energy in power generation and end-use sectors in the future, air pollutants emissions in the Below 2 °C scenario are lower than the Stated Polices scenario. That goes for all of the pollutants, except NH3, where agriculture is the main source of emissions. The emissions shown in Figure 9-13 are from all energy use, including industry, agriculture, and transportation.

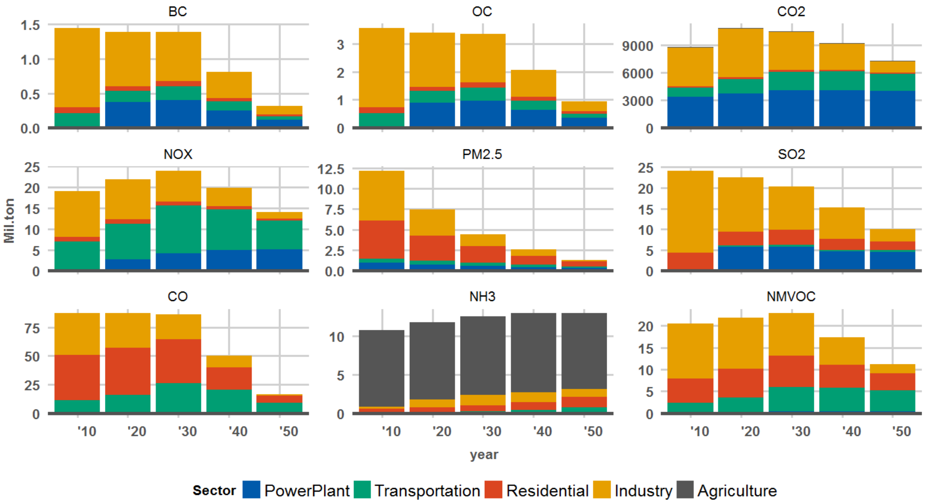
Figure 9-13 Emissions of pollutants to the air in two scenarios for China



The calculation of emissions from the energy sectors is based on the fuel consumption, estimated future conversion factors of energy technologies, and known requirements from the Chinese government regarding future emission control and standards.

With the assumptions of efficient implementation and enforcement of regulations and control, the emissions in China will drop from the current high level across all sectors. In Figure 9-14, the sectorial source for different emissions is shown in the Below 2 °C scenario for various air pollutants.

Figure 9-14 Emissions by sector in the Below 2 °C scenario



In the future the industrial, the transportation and the agricultural sectors will be main contributors to air pollution, while air pollution from the power sector will be reduced due to flue gas cleaning and due to reduced use of fossil fuel and replacement of coal with natural gas. Compared with the Stated Polices scenario the emissions from the power sector will be reduced significantly. Power sector will contribute with about half of the declining CO_2 emissions in the future.

Figure 9-15 shows the reduction in emissions over time in the Below 2 °C scenario by sector. The power sector is the main contributor to reducing BC, OC, CO_2, NO_x, and SO_2 emissions. The amounts of emissions in the two scenarios have been translated into changes in the concentration of pollutants in an atmospheric dispersion/transport model that simulates chemical reactions in the atmosphere and hence also the concentrations of secondary and harmful pollutants like $PM_{2.5}$ and ozone (O_3). The simulations of concentrations allow estimating the impact on human health from air pollution. The air pollution has a number of other negative impacts on agriculture, buildings, wildlife etc., besides human health. However, the impacts on human health in form of morbidity and mortality are considered as the most important in economic terms, and therefore this section only analyse those impacts.

Figure 9-16 shows the change in $PM_{2.5}$ and O_3 concentration in 2030 and in 2050. The diagram shows the difference between Below 2 °C scenario and Stated Polices scenario. The largest differences are found in 2050 and the largest differences between the scenarios are observed in the coastal areas of Eastern China, where the concentration levels are highest today.

Figure 9-15 Emissions reductions by sector in the Below 2 °C scenario

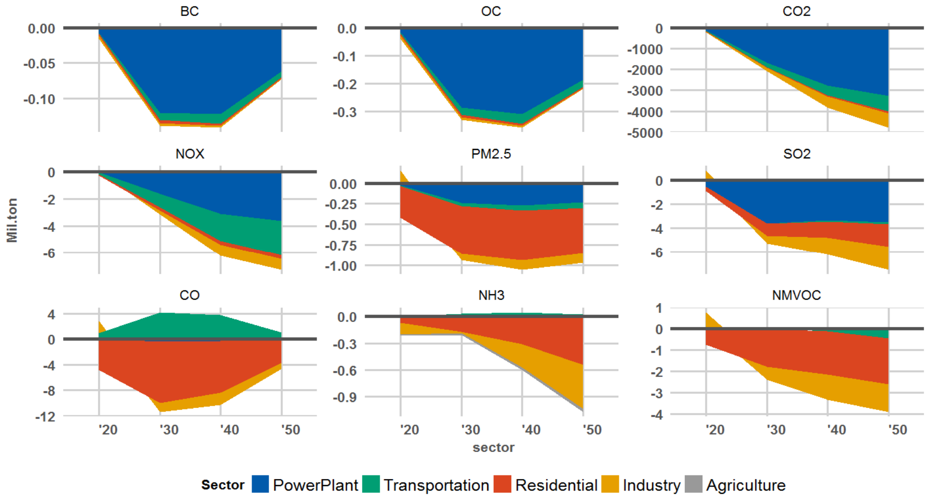
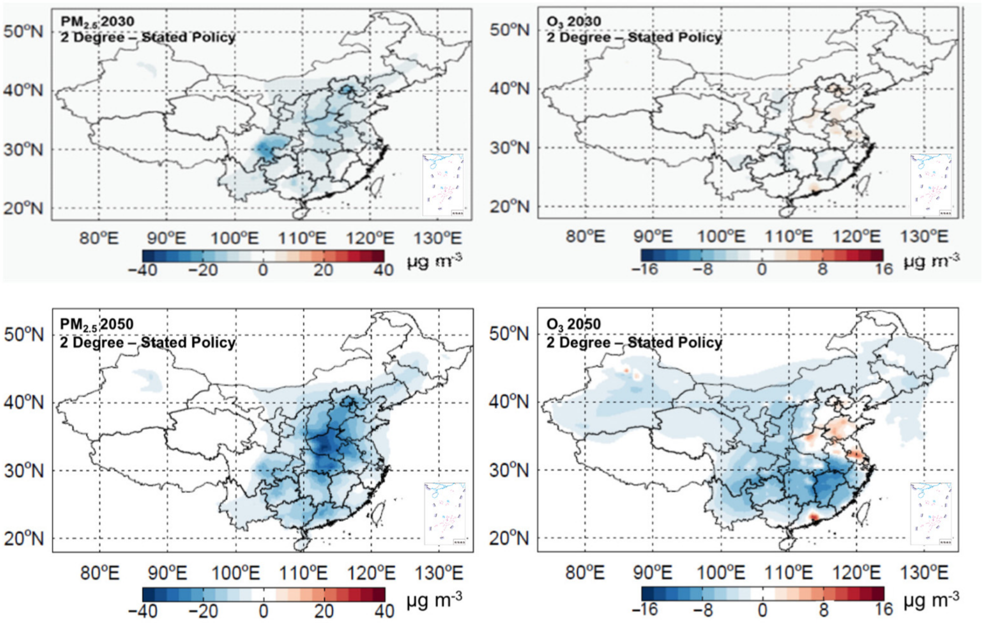


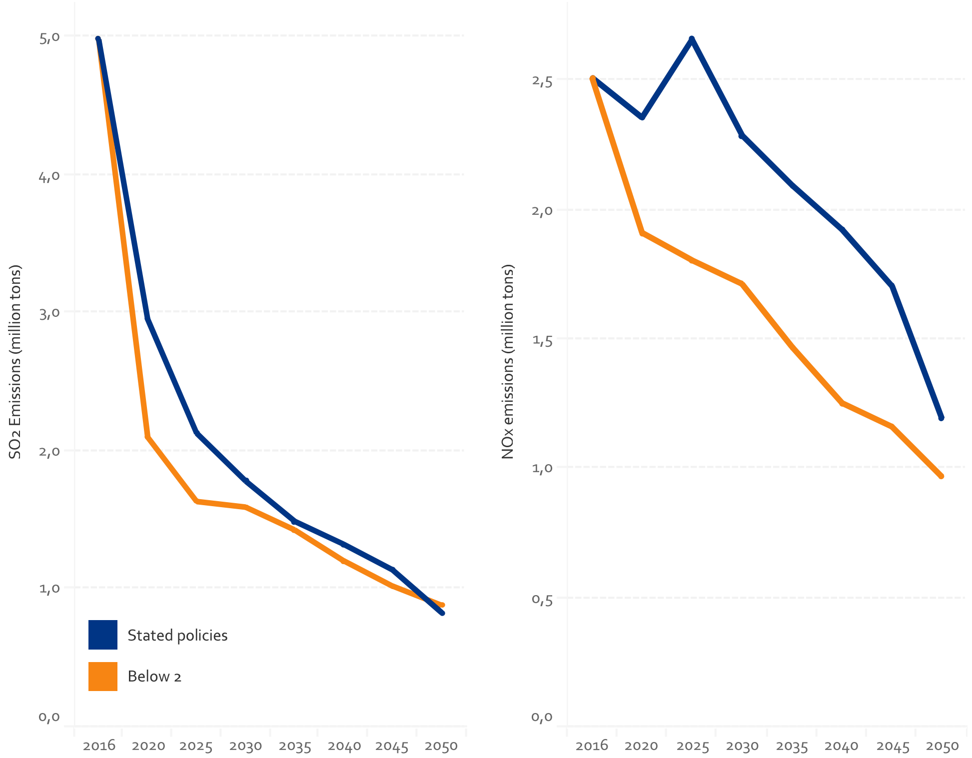
Figure 9-16 Differences in PM2.5 and O_3 concentration in 2030 and 2050 between the Stated Polices and the Below 2 °C scenario



Air pollution emissions from the power sector

PM2.5 pollution is a combination of several primary and secondary pollutants causing extensive health issues across China. SO_2 and NO_x emissions add to air pollution, both in themselves as well as they contribution to secondary PM2.5 pollution. In the Below 2 °C scenario SO_2 emissions from the power and district heating sectors are reduced by 84% in 2050 compared to 2016 levels, for NO_x emissions this is 71%. This results in an overall reduction across China and a particular benefit to the densely populated eastern provinces, where the air quality improvements will benefit many.

Figure 9-17 SO_2 (left) and NO_X (right) emissions from the power and district heating sectors from 2016 to 2050



The impact of local pollutants on human health

Air pollution is the fourth-largest overall risk to human health globally. Many of the causes to air-pollution can be found in the energy sector. The human health impact depends primarily on the level of concentration and the length of exposure to the pollution. Age is also an important factor when assessing the level of impact. Children and elderly people are the most exposed groups. Air pollution is an urgent social and public health challenge for China. From WHO's study[49] we know that around 1 million premature deaths today can be attributed to outdoor pollution in China. Average life expectancy in China is reduced by almost 25 months because of poor air quality, according to WHO.

Consequently, the selection of pathway for China's energy sector has a profound impact not only for CO_2 emissions and global warming, but also directly for the mortality and morbidity in China. The following section quantifies this impact in numbers and economic costs using 'state of the art' methodologies. The economic costs of morbidity and mortality related to outdoor air-pollution will be used as indicators for human health impacts. It should be noted that this approach does not cover all economic costs related to air-pollution, only the major health impacts, as previously mentioned.

Renewable energy reduces morbidity

Exposure to air pollution may lead to a range of serious diseases and premature death. Risk of morbidity is defined as the risk to suffer from one kind of disease in one year. Figure 9-18 shows the impacts of air pollution on the risk of morbidity, i.e. each person's risk of catching outdoor air pollution-related diseases, in forms of either outpatient or hospital admission in a year. The figure shows that both scenarios will contribute to a reduction of morbidity, however the reduction of is much higher in the Below 2 °C scenario. The figure also shows that the health benefits from development of renewable energy are much higher in 2050 than 2030. In 2030 in the Below 2 °C scenario, the national total avoided morbidity is 34.4 million cases, whereas it increases to 140 million cases in 2050, as shown in Figure 9-19.

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[49] World Health Organisation, Burden of disease from ambient and household air pollution for 2012, Summary of results, Geneva 2014

Figure 9-18 Human health impacts from air pollution - risk of morbidity

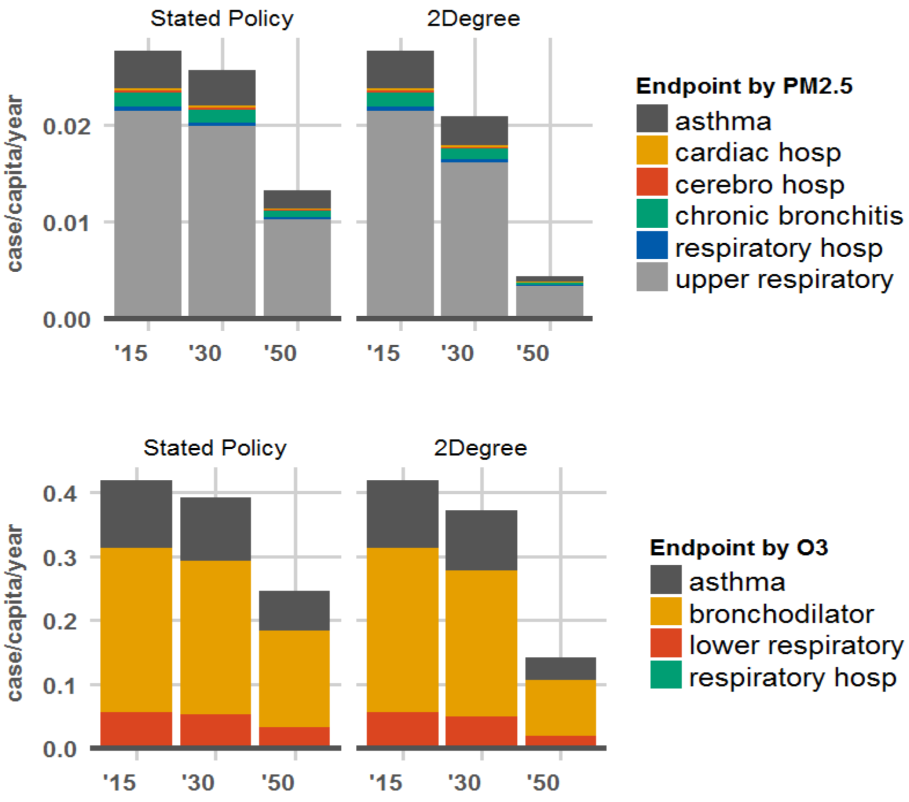
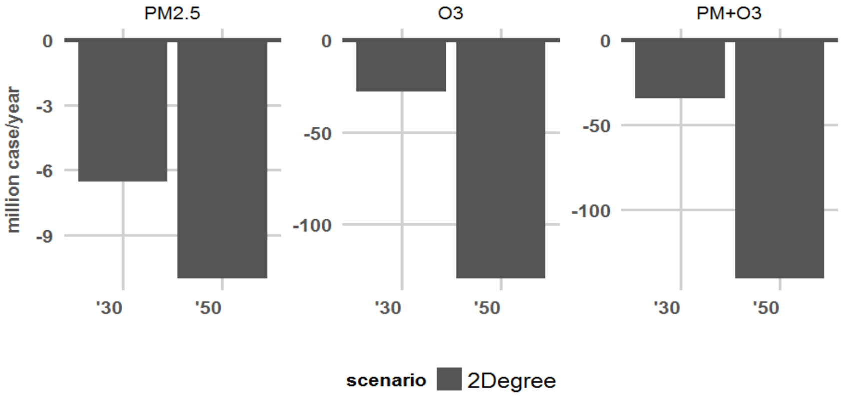


Figure 9-19 Avoided morbidity in the Below 2 °C scenario



Air quality varies a lot in China because of different air pollutants emission levels, specific geographic conditions and differences in age composition. The provincial disparity in Figure 9-20 and Figure 9-21 show that in the Stated Policies scenario, Qinghai, Sichuan, Beijing, Gansu and Tianjin are among the regions with highest health impacts from $PM_{2.5}$ and ozone pollution.

In the Stated Policies scenario, annual morbidity risk is 90% and 85% in Qinghai, 77% and 58% in Sichuan, 61% and 45% in Beijing, 62% and 52% in Gansu, 50% and 36% in Tianjin in 2030 and 2050, respectively. By contrast, in the Below 2 °C scenario, Guizhou, Jiangxi, Shaanxi, Shanxi, Hunan are among the regions with most benefits from reduced adverse health damage. The avoided morbidity risk is 5.6% and 19% in Guizhou, 5.6% and 16% in Jiangxi, 4.8% and 13% in Shaanxi, 4.5% and 16% in Shanxi, 5.1% and 21% in Hunan in 2030 and 2050, respectively.

Ozone pollution is an increasingly serious air pollution issue in China, especially in the urban areas. Ozone has negative impacts on human health. The national average annual risk from ozone pollution is much higher than that of $PM_{2.5}$. In 2015, each person suffered 2.1 times from symptom to the deceases listed in Figure 9-18. Unlike the decreasing trend of $PM_{2.5}$, health damage of ozone will continue to increase to 2.3 in the Stated Policies scenario. However, in the Below 2 °C scenario, the per capita number of cases will drop to 1.94 in 2030, which is lower than the current level.

Figure 9-20 Health impacts and benefit on risk of morbidity from PM2.5 and O3 in 2030

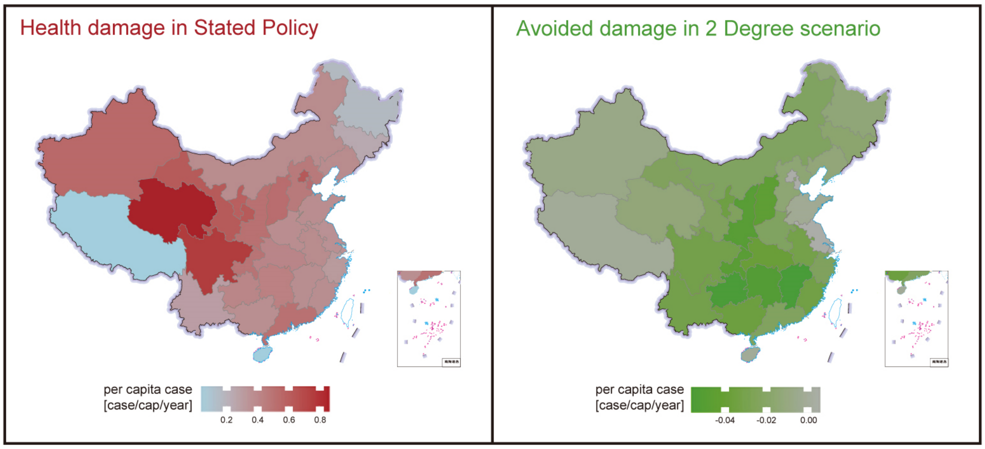
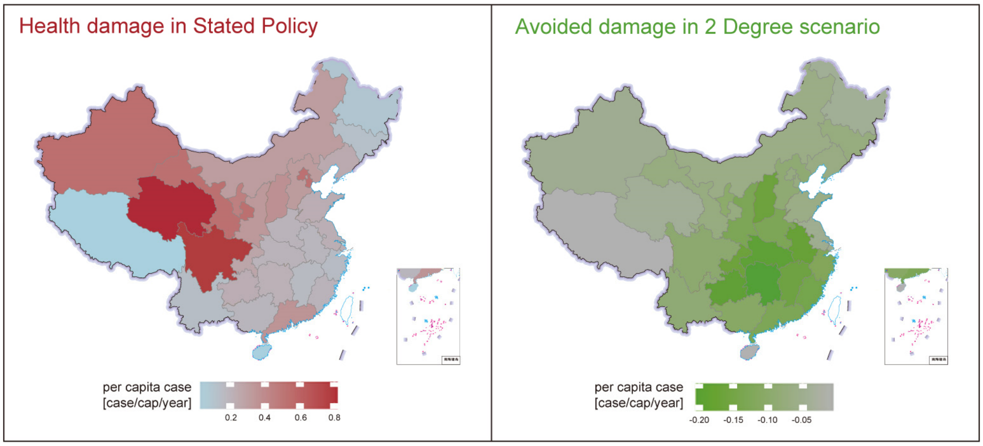


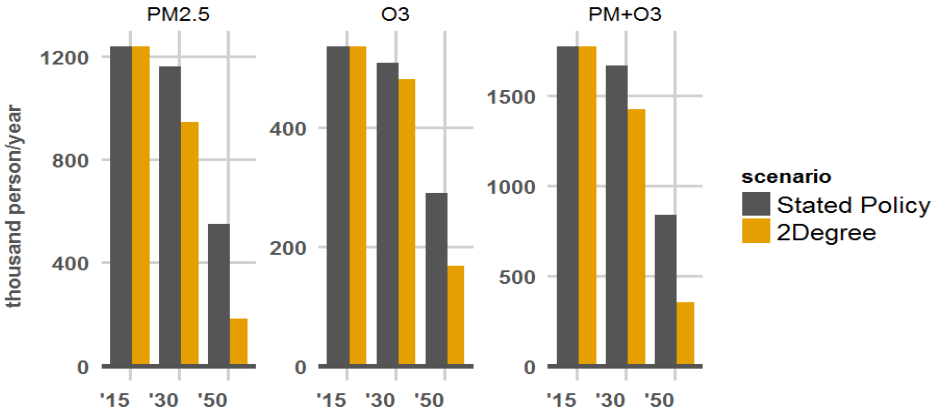
Figure 9-21 Health impacts and benefit on risk of morbidity from PM2.5 and O3 in 2050



Renewable energy reduces mortality

Increased premature mortality is the most serious human health impact of air pollution. Even relatively low levels of air pollution may pose risks to health because of the large number of people exposed. Figure 9-22 present the impacts on mortality in the two scenarios. The total premature mortality caused by air pollution is estimated to 1.8 million people in 2015 in China, including 1.2 million from $PM_{2.5}$ and 0.6 million from ozone. Premature mortality is 1.7 and 1.4 million in the Stated Polices and Below 2 °C scenarios in 2030. While in 2050, premature mortality decreases to 0.84 and 0.35 million in Stated Polices and the Below 2 °C scenarios, respectively, far below the mortality reported in 2015.

Figure 9-22 Premature mortality caused by PM2.5 and Ozone in two scenarios



Mortality from $PM_{2.5}$ and ozone changes a lot in China, as shown in Figure 9-23 and 9-24. In 2030, most premature deaths occur in Henan (266,512 and 229,622 in the Stated Policies and 2 Degree scenarios, respectively), followed by Shandong (157,000 and 142,000), Hebei (133,500 and 115,200), and Anhui (100,200 and 85,600) provinces. In 2050, mortality decreases in most of provinces in China. The national total avoided premature deaths are 244,000 and 490,500 in the Below 2 °C scenario in 2030 and 2050, respectively, and most avoided premature deaths are found in Henan (37,000 and 85,000 in 2030 and 2050, respectively), Shandong (15,000 and 38,000), Hebei (18,000 and 36,000), and Anhui (14,000 and 37,000) provinces.

Figure 9-23 Health impacts and benefit on mortality from PM2.5 and O3 in 2030

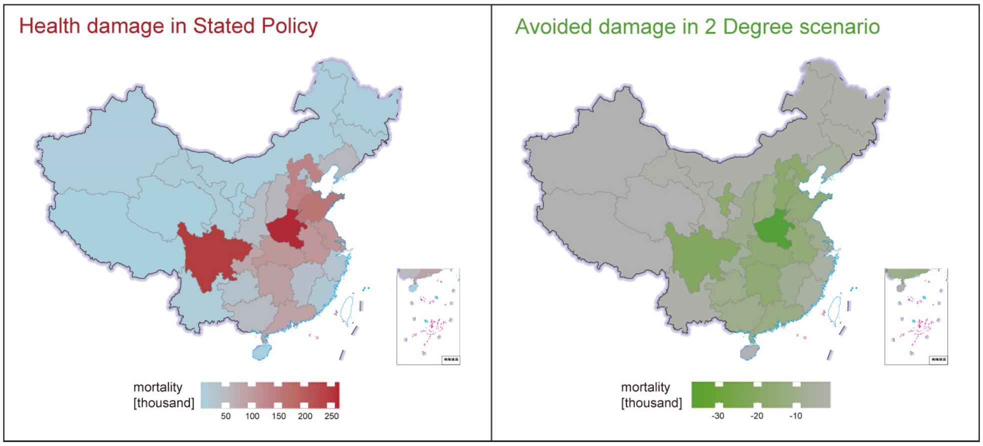
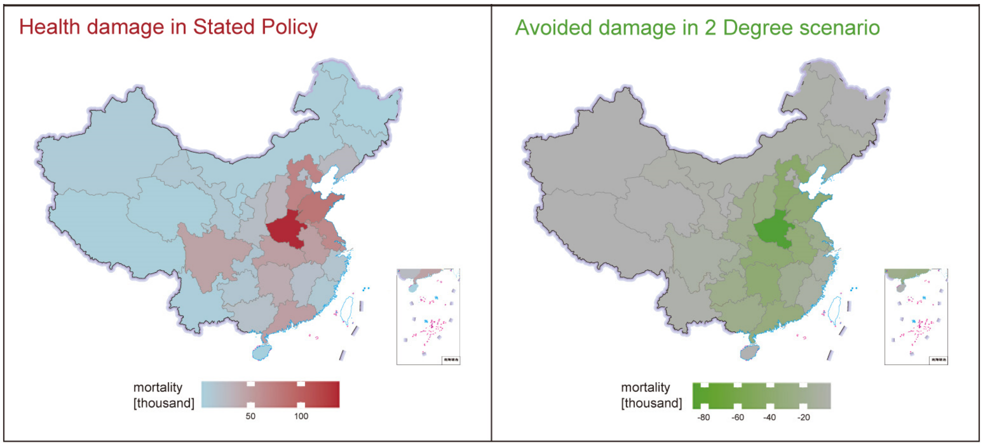


Figure 9-24 Health impacts and benefit on mortality from PM2.5 and O3 in 2050



Monetary evaluation of morbidity and mortality

The monetary evaluation of the above described damage caused by local air-pollution is composed of three items:

- Medical expenses related to treatment of diseases
- Welfare loss from premature deaths
- Loss of working hours leading to a reduction in GDP

Medical expenses

In 2015, medical expenditures related to air pollution are estimated to 53 billion RMB, equivalent to 39 RMB per capita. For comparison, the total medical expenses in China were 1 050 billion RMB in 2014[50] corresponding to 750 RMB per capita. Medical expenses comprise medication, treatment at hospital, treatment outside hospitals and patient-fees related the diseases and symptoms listed above. The estimation of the related expenditure is based on statistics and the results shown in Table 1-2. The expenditures to diseases related to ozone are by far the highest.

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[50] China Health and Family Planning Yearbook 2015

Table 1-2 Medical expenditure related to PM2.5 and ozone in China

Total National Medical Expenses	2015	2030	2050
Stated Policies (Billion RMB)	53	100	96
Below 2 °C (Billion RMB)	53	91	52
Medical expense per capita related to air-pollution			
Stated Policies (RMB/cap)	39	74	77
Below 2 °C (RMB/cap)	39	67	41

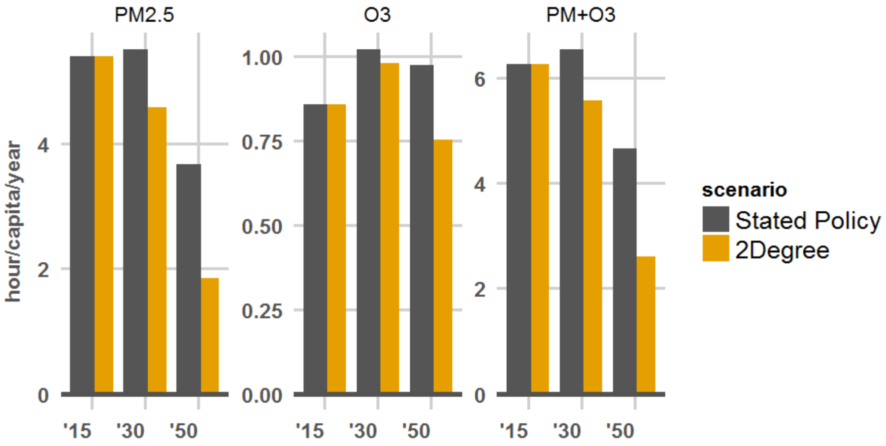
The medical expenditure related to air-pollution comprised app. 53 billion RMB in 2015 and will increase to 100 billion RMB in 2030, because the growth in population will outbalance falling risk of morbidity, and fall 96 billion RMB 2050 according to the Stated Polices scenario. In the Below 2 °C scenario they will decrease more rapidly after 2030, because the reduction in air pollution outbalance the population growth in this scenario and only comprise around half of the expenditure in the Stated Policies scenario. The medical expenses per capita follow the same pattern.

Working hour loss

The morbidity and mortality affect the population in age groups typically working and earning income (age 15 – 65). The work time lost by increased morbidity and premature mortality is an economic loss for the society. In 2015 the national per capita loss from $PM_{2.5}$ and ozone related impacts was 6.5 hours and it will decrease in 2030 and 2050 in both scenarios. The work time loss is only about one third in 2050 in the Below 2 °C scenario compared to the Stated Polices scenario. The regional differences in these results are also important. In the developed regions with high population density the work hour loss in total and per capacity are highest.

The work hour loss from $PM_{2.5}$ is much higher than from ozone, please refer to Figure 9-25.

Figure 9-25 Per capita work hour loss in two scenarios



The damage caused by working loss is estimated by the increase in GDP that the 'missing' working hours would have produced, and is calculated in a macroeconomic model.

Monetary evaluation of premature mortality

The societal loss related to premature mortality is estimated with so-called Value of Statistical Life (VSL), which is an expression of the individual willingness to pay to avoid premature death. The VSL is based on Chinese surveys and studies[51]. The VSL is adjusted for each province in order to reflect regional differences in GDP. The average VSL for China in this study is 250 000 USD in 2010 price level.

Total damage costs from local air-pollution

Table shows the result of the monetary evaluation of the damages caused by local air pollution. The total costs are estimated to 4,876 billion RMB in 2030 increasing to 4,934 billion RMB in 2050 in the Stated Polices scenario and to 2,214 billion RMB in the Below 2 °C scenario. The largest item is the increased mortality. There is app. 2,800 billion RMB.

The air-pollution caused by the energy sector is responsible huge losses in the society in terms of increased medical expenditures, increased mortality and loss of work hours due to morbidity and mortality. The table below summarises the impacts on human health in the two scenarios.

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[51] (Xie, X., 2011)

Table 9-3 Overview of damage costs from local air-pollution in China for two scenarios in Billion RMB

Billion RMB price-level 2015	2015	2030		2050	
Scenario		Stated Polices	Below 2 °C	Stated Polices	Below 2 °C
Increased morbidity	53	100	91	96	52
Increased mortality	4,708	6,786	5,789	4,503	1,882
Lost working hours	115	256	217	335	194
Total	**4,876**	**7,143**	**6,098**	**4,934**	**2,128**

Externalities – costs per unit of pollutant

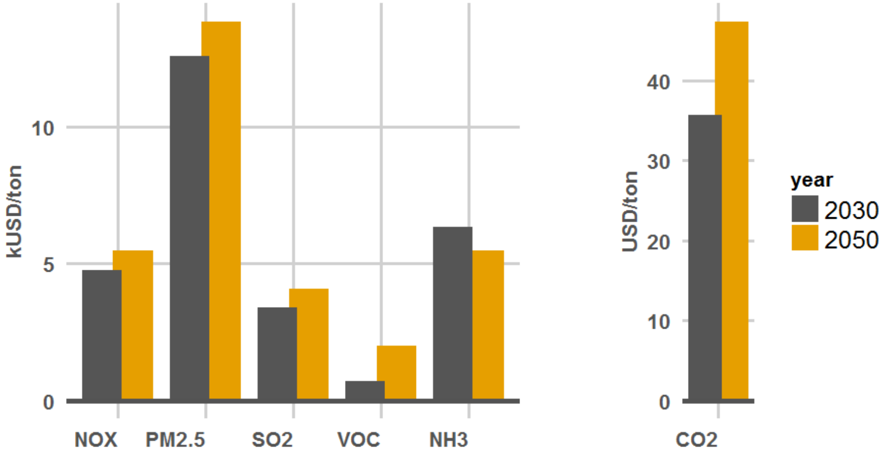
In the above we have been looking at the various damages caused by air pollution coming from the energy sector and assessed the costs/loss these damages represent for China in monetary terms. The following section will address the costs per unit of local pollutants in 2030 and 2050. This number is useful assessing and making the costs associated with environmental externalities from fossil fuels visible.

The estimation of economic costs per unit of pollutant is important information for the regulation of fossil fuel use. Uses of fossil fuels are mainly controlled through fuel/emissions standards and/or taxation. The level of environmental tax on the fossil should reflect the costs of their contents of harmful emissions. Inclusion of externalities is also important information when comparing of the costs of different power production technologies (LCoE). Normally the costs of externalities do not appear, but only the directly observable expenditures are presented. Internalising the external costs will provide a fairer comparison from a societal point of view.

By simulations with small changes in emissions in the metrological model it is possible to estimate the marginal damage costs of selected emissions. It should be noted that the estimates are results of simulations and does not necessarily corresponds with the numbers that can be obtained from programmes measuring the actual concentration of the pollutant in the proximity of power plants and other stationary emission sources. It should be noted there is considerable uncertainty associated with these calculations.

Figure 9-26 shows net economic benefits (national average) of reducing one ton of emissions of NOx, $PM_{2.5}$, SO_2, VOC and NH_3 in 2030 and in 2050. The economic benefits are relatively stable from 2030 to 2050 for the pollutants, except VOC. For NO_x it is around 5 000 USD, PM2.5 around 1 300 USD, SO_2 around 3 800 and for NH_3 around 7 700 USD per ton. The damage costs of VOC are increasing from 730 USD/ton in 2030 to 2000 USD/ton in 2050.

Figure 9-26 Reduction of economic loss associated with per unit of pollutant (1000 USD/ton and USD/ton) in 2030 and 2050



The numbers provided for damage costs reflect the level of taxation that would be advisable from an economic point of view and that China should aim to achieve over the coming 10-year period.

It should be added that there are huge regional differences of the economic benefit per ton of saved emission, especially for PM2.5. The reduction benefits are biggest in the central China where the PM2.5 pollution concentrations are highest. Other factors like population density, age distribution, industrial and agricultural structure and metrological conditions also play a role. The future taxation of fossil fuels should reflect these differences.

9.4 Water consumption in the power sector

Renewable energy can mitigate stress of water resources in China. The following analysis is based on the two CREO scenarios and is further detailed in the publication "How renewable energy development saves water consumption in China. A provincial level scenario towards 2050" Dai Hancheng and Li Minquan, August 2017.

The aggregated water consumption from electric power generation in the Stated Polices scenario and the Below 2 °C scenario is shown in Figure 9-27. The total water consumption will decrease despite a doubling of the power production due to technology improvements. The water consumption in the Below 2 °C scenario is much lower than in the Stated Polices scenario.

Figure 9-27 Aggregated water consumption from power generation in China in the Stated Polices scenario and the Below 2 °C scenario with different assumptions regarding water intensity

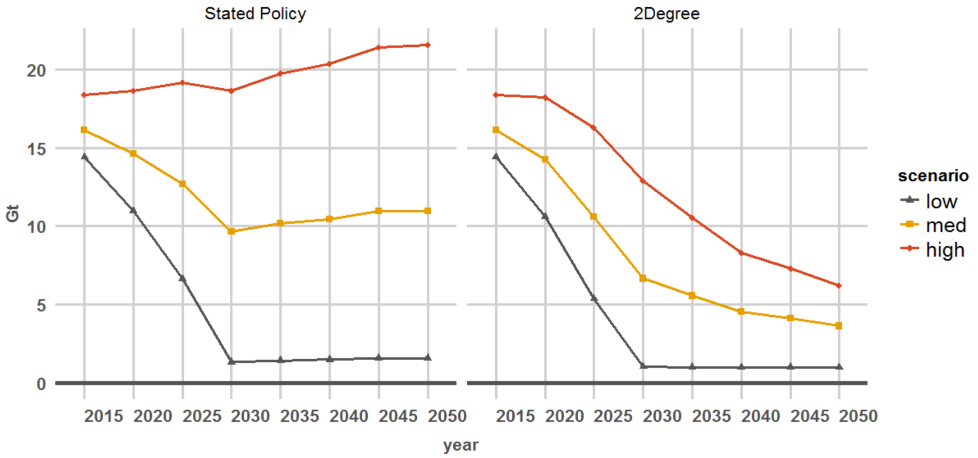


Figure 9-27 shows that the current water consumption in the power sector is estimated to between 15 and 18 Gt depending on the assumptions regarding water intensity for the various power production technologies. The median scenario represents the 'best guess' of water intensity. In the case of the median scenario for the Stated Policies scenario the water consumption will decrease from 16 to 10 Gt between now and 2030. Subsequently it will rise to 11 Gt in 2050, which is still lower than in 2015.

In the Below 2 °C scenario (median) the water consumption decreases from currently 16 Gt to 4 Gt in 2050, while it is estimated to around 6 Gt in 2030. It is noteworthy that in the Stated Polices scenario it will not be possible to sustain the downward trend in water consumption after 2030, while this is possible in the Below 2 °C scenario.

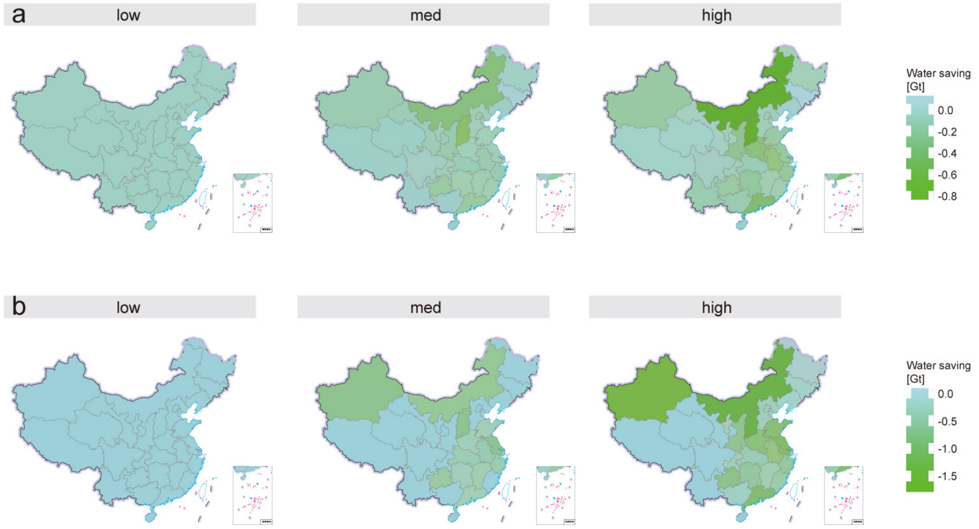
The replacement of coal technologies with renewable energy is causing reductions in the water consumption, because renewable energies, like wind and solar technologies, have much lower water intensity than thermal power production technologies. However, the water consumption from natural gas and nuclear power production will increase from now to 2050 and might surpass coal based technologies in being the major water consuming technologies. This is especially true for nuclear power plants located in inland China, as opposed to the coastal areas where sea water can be used for cooling. From a water-consumption perspective inland nuclear development is therefore not attractive.

There are dramatic differences in water consumption among the provinces of China. In 2015, water consumption from electric power generation was geographically concentrated in the three northern areas and coastal areas. It will continue to be concentrated in these areas up to 2050. Inner Mongolia, Guangdong, Jiangsu, Shanxi, Shaanxi and Xinjiang will continue to be the largest water consumers in China, which is a great challenge for sufficient water supply in these areas. This is mainly because the existing coal-fired power plants are concentrated in these areas.

Figure 9-28 shows the water savings potential in the regions for different water intensities (low, med, high) in the Below 2 °C scenario compared to the Stated Polices scenario, i.e. the difference between the two scenarios by region.

The incompatible geographical distribution of water resources and water consumption in the power sector will continue to pose great stress in water scarcity in China. The installed capacity of thermal power plants in North China accounts for nearly 60%, while the water resources only accounts for app. 20% of the nationwide available water resources. Also in the Western part of China, the water resources are relatively scarce while electric power sector consumes a lot of water resources. Renewable energy development will be beneficial to lower water consumption in the provinces under great water stress. This will be helpful to ensure both electricity and water supply in China and avoid trade-offs between the two when water resources are low and power demand is high. The geographic location of the power generation in the future is however also an important element in reducing future water stress in China.

Figure 9-28 Water savings in the Below 2 °C scenario compared with Stated Polices scenario for different water intensities in 2030 (top) and 2050 (bottom)



To sum up, the combination of technology development and structural changes in the power generation are the main drivers for a decrease in water consumption from now to 2030 in both scenarios, despite increased power supply.

The comparison of the two scenarios emphasise the importance of renewable energy in water conversation from now to 2050. Technological development in coal power plants is also essential, especially during the first half of the period, i.e. up to 2030, after which it can be expected that the speed of intensity improvements will flatten out. The substitution of thermal power with renewable energy will play an outstanding role in mitigation the pressure of water consumption in the northern and western provinces. The choice of cooling systems in coal, natural gas, and nuclear power plants are also very important for reducing water stress.

Currently there are no specific requirements for water conservation in China's power sector. It will be important to set targets for water conservation in the future and create economic incentives for using the most efficient technologies in terms of water consumption. The major part of the water consumption is related to cooling and there are dramatic differences between the water intensity in different cooling technologies.

10 Final energy demand outlook

Future energy demand is highly driven by economic growth and social progress. China has grown rapidly - often at double-digit rates - for more than three decades by following a strategy of fast industrialization, especially for the heavy-industrial sector and energy-intensive manufacturing, it also heightened problems of tremendous increase in energy consumption, intensified pollution and greenhouse gas (GHG) emissions. Recognizing these difficulties, the economic strategy has changed. China is now adapting to a new phase of economic development - a "new normal" - shifting the balance of growth away from heavy-industrial investment and toward domestic consumption, particularly of services. Meanwhile, its energy system is also evolving towards a more advanced, more reasonable and cleaner phase through emerging changes. Enhanced measures to improve energy efficiency and reduce emissions are more and more put on the political agenda. Accelerating progress of clean and renewable technologies is showing strong potentials to support a rapid growth of renewables. These changes may profoundly influence the energy supply and demand pattern in the future. In this chapter, the changes in future energy demand and fuel structure in different economic sectors in China are analysed, based on what can be considered as reasonable trends in economic growth, social development, industrial upgrading, energy efficiency progress and energy technology revolution up to 2050.

10.1 Methodology for final energy demand

Model tool

To analyse and forecast changes in future final energy demand accurately, China National Renewable Energy Centre 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. Such assumptions defined in the end-use sectors include both social-economical parameters like future population, urbanisation rate, and technology parameters like efficiency, annual activity level, fuel mix which are drawn from in-depth analyses of future technology development, energy production and energy end-use characteristics in different sectors, namely, industry, buildings, transport, agriculture and construction. Key parameters, like primary demands and import-export needs, are calculated by the system.

A large quantity of statistical and forecasting data is required for operating the model. Such data is mainly sourced from China Statistical Yearbook, China Energy Statistical Yearbook Data, as well as relevant forecasts made by main industrial research institutions and leading countries. Among these data, the forecasting data from Chinese Government or large international organizations are used for the economic and social forecasting model and such technical data including energy efficiency are adopted from international leading level of relevant technology or field. With remarkable progress in technology industry in past decades, China is expected to be a global leader in many fields in 2050. It is hereby assumed that if China will steadily promote technology industry upgrading from now to 2050, and actively deploy and apply internationally advanced technologies now, it would become a global leader in many fields in 2050.

Since the parametric assumption, analysis method and analytical focus of different sectors vary due to the difference in their energy consumption patterns and economic development indicators, the model will make specific analyses on particular problems in following sectors.

Scenario setting

This study has two core scenarios, i.e. Stated Policies Scenario and Below 2°C Scenario. The first scenario, Stated Policies, illustrates the implication of a continuation of the current Chinese energy and environmental policy. The second scenario, the Below 2-°C, analyses the implications of the Chinese commitment to the Paris Climate Agreement's aim to "holding the increase in the global average temperature to well Below 2 °C above pre-industrial levels".

CREAM END-USE projects both scenarios to perform equally well in increasing energy efficiency as well as economic trends, as China's policies already have this in focus. The scenario differences arise from assumption differences in the penetration level of energy efficiency technologies/renewable energy technologies, which differentiates primarily through the fuel types consumed to deliver the different energy services and results in the differences in future fuel demand and energy structure. In the Stated Polices Scenario, by 2050, China's energy intensity has a downward slope towards the level of Organization for Economic Co-operation and Development (OECD), Europe (EU25), US or Japan. In the Below 2°C Scenario, stronger clean energy actions should be taken to promote the energy revolution and ensure sustainability transitions. Parametric assumptions like electrification rate, fuel mix and technology penetration level in subsectors are set based on a combination of international and Chinese studies and expert opinions, according to their specific industrial characteristics and renewable energy resource adoption potential.

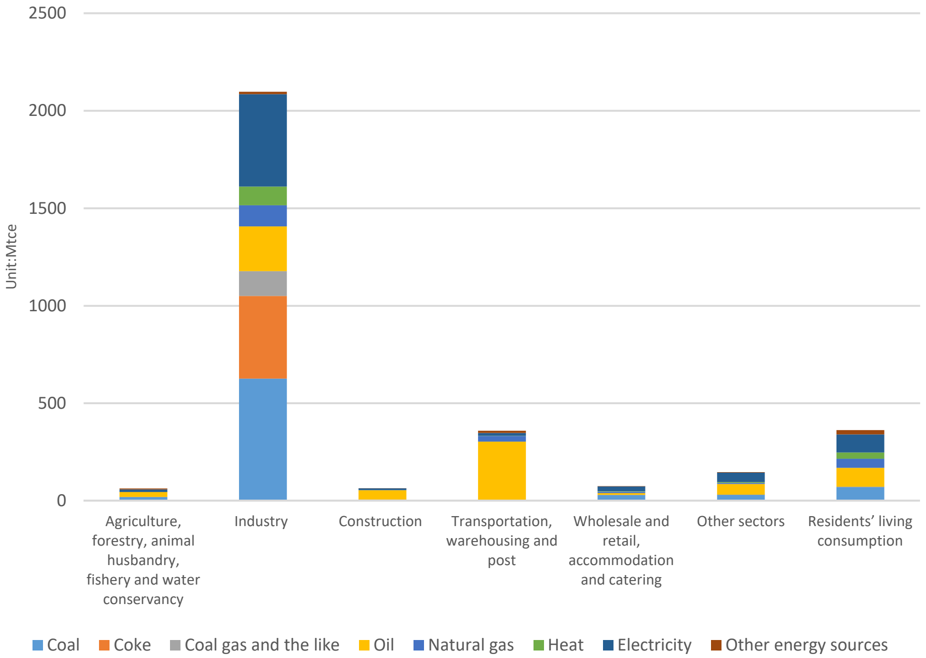
It should be noted that since energy efficient practices are generally a superior way to ensure clean, cheap, and as reliable energy supply and increasing energy efficiency is a priority for the Chinese government, the same ambitious energy efficiency policies and measures are in place in both scenarios. However, in the Below 2 °C scenario, other more progressive measures, are assumed implemented in order to ensure a CO_2 reduction in compliance with the Paris agreement. These include a faster and more thorough electrification, a quicker phased-out of coal fleets and a higher share of renewable for direct use.

Energy consumption and structural changes

Industry has been the main driving force of national economic development over the past 30 years, and industrial energy consumption took up 66.1% of the total final energy consumption in China in 2015. Rapid development of industry causes a sharp increase in energy consumption, which drives economic development in return. The industrial economy of China has made significant contributions to national economic development, accelerating urbanization process and improvement of people's living quality in China by supporting construction of new infrastructure, buildings and cities. It also increased the wealth of the country substantially, making China the 2nd largest economy in the world and fostering the world's largest middle-class. The fast urbanization process and rising wealth present challenges for China as it continues to reform its future energy consumption pattern: massive transformation towards a service-driven economy, which means gradual increase in the demand for electrification and clean energy; growing vehicle use, which leads to increasing energy demand for transport sector; growing numbers of urban residents, which requires many advanced energy services, such as district heating and cooling, to be applied to a wider scale; in addition, there will be also an increase in energy consumption related to agriculture and construction in China.

The energy demand of China was mainly self-sufficient with a low energy consumption in the past. Now the situation has changed substantially in a period of less than one generation, where China has become the second largest energy consumer in the world with unprecedented growth and where it plays a very important role in global energy market. According to data of *2016 China Energy Statistical Yearbook*, the total energy consumption of China in 2015 was 4.36 billion tce, and the final energy consumption was 3.17 billion tce excluding processing and conversion losses, recycling, as well as transmission and distribution losses. This study analyses and forecasts future final energy demand based on the energy demand and consumption pattern in 2015.

Figure 10-1 Final energy demand in main fields of China in 2015 (10,000 tce)



At present, the energy system of China still relies heavily on fossil resources, in particular coal. Coal is the primary energy in the energy system of China, even when disregarding power generation and heating, as coal-fired boilers are used widely by heavy industry plants, commercial and residential areas. In 2015, the final consumption of fossil fuels took up approximately 72.6%, the total consumption of coal, coke and coal gas took up approximately 42.3%, and the direct use of coal took up approximately 24.9%. China has considerable power demand, specifically in industry and residential sectors. However, the utilisation of non-power renewable energy, including biomass, solar energy and geothermal energy, only takes up a small portion of final energy consumption currently, and most are used for heating for residents in rural and small urban areas.

As shown by the energy development history of developed countries, energy demand tends to grow with the industrialisation and urbanisation process and summit just after completion of industrialisation and urbanisation. Intensity of final energy consumption also tends to rise first to decline later. China is currently at the middle-late stage of industrialisation and urbanisation, where significant changes take place in the economic growth pattern and energy consumption pattern. Though energy demand is still increasing, with various industry technologies accelerating to catch up with and surpass the advanced countries' levels, the energy efficiency is significantly improving and energy intensity is starting to decline, which brings new opportunities despite of the pressure to increase energy supply. China should pay equal attention to energy demand as well as supply side, optimize the economic and industrial product structure, cultivate green clean energy consumption patterns, encourage innovations in energy supply patterns and actively adjust the final energy consumption structure. Specifically, it is necessary to control coal consumption by end users, promote coal substitution, further improve electrification and energy efficiency, raise power and renewable energy utilisation in fields including construction transportation and industry, reinforce the construction of green and low-carbon urban, transportation and industrial system, and popularise heat utilisation of clean power and renewable energy as well as other clean energy sources so as to form a coordinated energy production and consumption pattern among population, resources and environment.

10.2 Industry Sector

Industrialisation process and energy consumption

Industry is the cornerstone of China's economy and also its largest final energy consumption sector. According to *China Energy Statistical Yearbook*, in 2015, the final energy consumption of industrial sector in China was 2.097 billion tce (including raw material consumption of 214 Mtce), taking up 66.1% of the total final energy consumption. Meanwhile, the energy consumption of six high energy-consuming sectors, namely steel, nonferrous and non-metallic mineral product industry, petroleum processing, coking, chemical industry and power, took up 80% of the total energy consumption, where the steel industry alone took up more than 30%.

However, as shown by experience of developed countries and newly industrialized countries, the primary position of heavy industry in industrial field is a basic characteristic for industrialization coming into middle-late stages. Since the beginning of this century, the heavy industry production of China has maintained above 70% of the total industrial production but the increasing trend started to slow down after 2008 and the proportion reached the peak at 71.8% in 2011. As research shows, 19 out of China's most important 24 branch industries have reported overcapacity, including heavy industry and manufacturing—where overcapacity is most obvious, for example, 40% excess capacity in Iron and Steel industry, 58.4% in Aluminium, 200% in Coke, 30% in Electronics manufacturing, and 100% in Textiles. Many enterprises expect a painful adjustment period of reducing stock and deleveraging in a short-term and reducing production in a medium and a long term. The growth rate of industrial sector in China has been decreasing in recent years, down from 12.1% in 2010 to 7% in 2014. With the entering into a new economic phase, the rapid development in heavy industry will slow down. Additionally, in conjunction with rising production costs, rapid development of smart and automatic technologies, China's manufacturing industry is gaining ground in global competitiveness, and the basic feature of the country's trade relations with developed countries is transforming from a vertical division of labour into a mixture of cooperation and competition. It is expected that, driven by industrial transformation and structural changes since the 13thFYP, the country's heavy industry will cease to grow and enter stationary or decline phases, with decreasing heavy and low value-added industry productions. The future economic momentum will mainly come from Hi-tech industry including advanced manufacturing, whose share will be increased continuously.

As the growth of heavy industry slows down, high energy-intensive sectors will consume less energy accordingly, which is mainly due to two factors, i.e. reduction of total industrial output and progress in energy efficiency. Adjustment strategy for industrial energy consumption will be consistent with the overall energy structure adjustment which follows three steps:

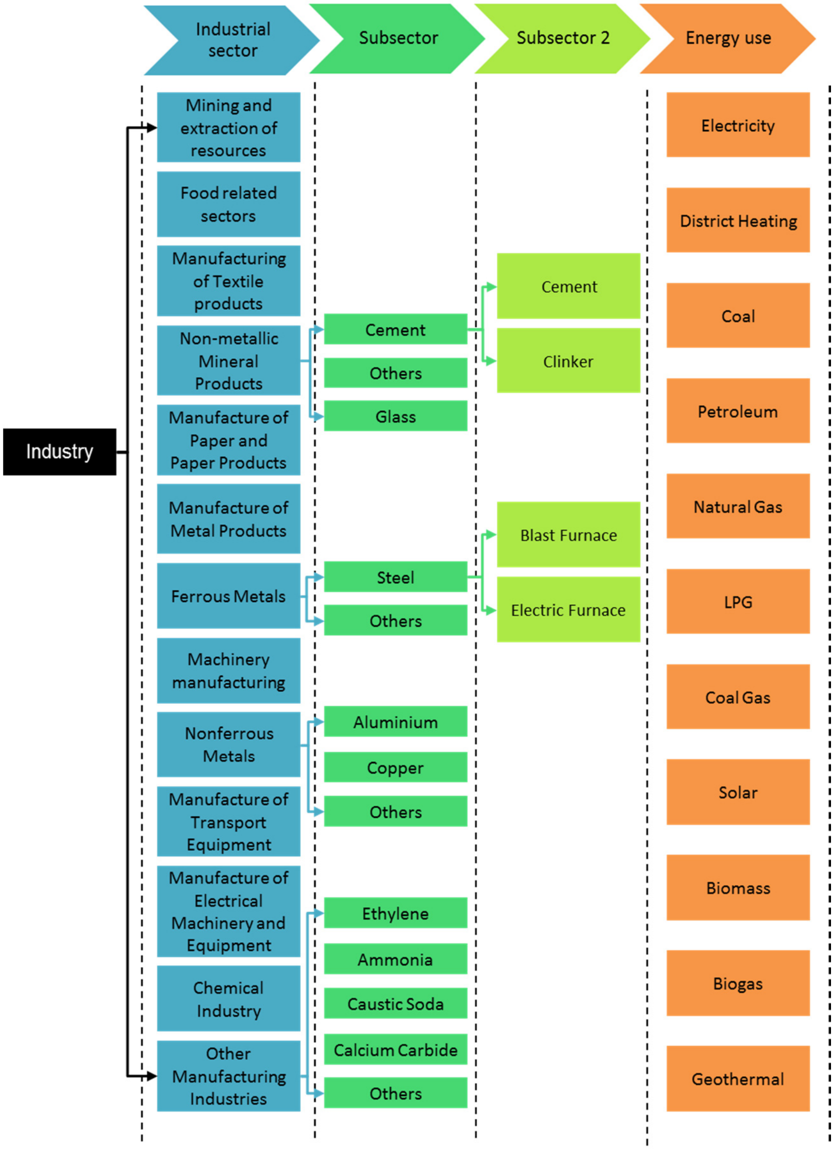
1. Significantly lower the proportion of coal,
2. Increase the share of high quality clean energy including natural gas,
3. Upgrade energy technology and promote the electrification levels.

Therefore, the trend of adjustment of the industrial energy structure during 2020~2050 is expected to be as follows: the total industrial energy consumption will be steadily decreased, while the proportion of coal will be continuously reduced, that of clean energy (such as electricity) will be gradually increased, and the usage of industrial waste heat and low-temperature solar heating will function as substitutions in final energy supply.

Industrial sector's final energy demand analysis framework

The CNREC END-USE Model divides industry into many subsectors of different varieties and activity levels. The structure of final demand model of industry is shown in Figure 10-2.

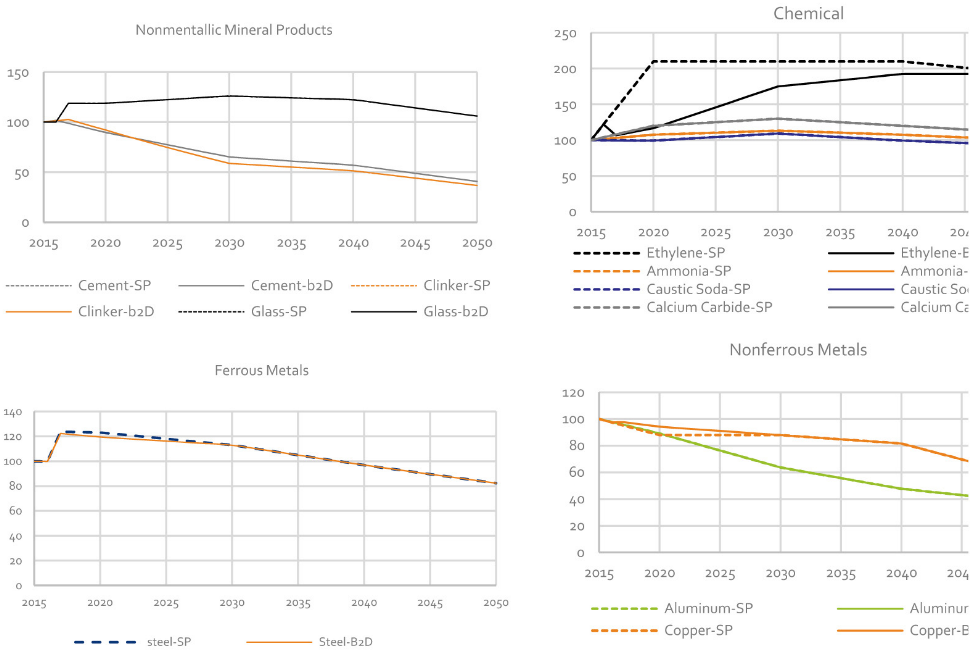
Figure 10-2 industrial sector's final energy demand model framework



The CNREC END-USE Model builds its activity levels according to real-world productions. This study forecasts the productivities of various branches and the technical energy intensity in different subsectors in the future. Due to the high number of products and technologies involved, main products in each sector and the relative values to their benchmark year production are mainly used here to represent changes in the sector's activity level, and the relative values to benchmark energy intensity of main technologies in each sector is used to represent changes in energy consumption, based on which the final energy demand is analysed.

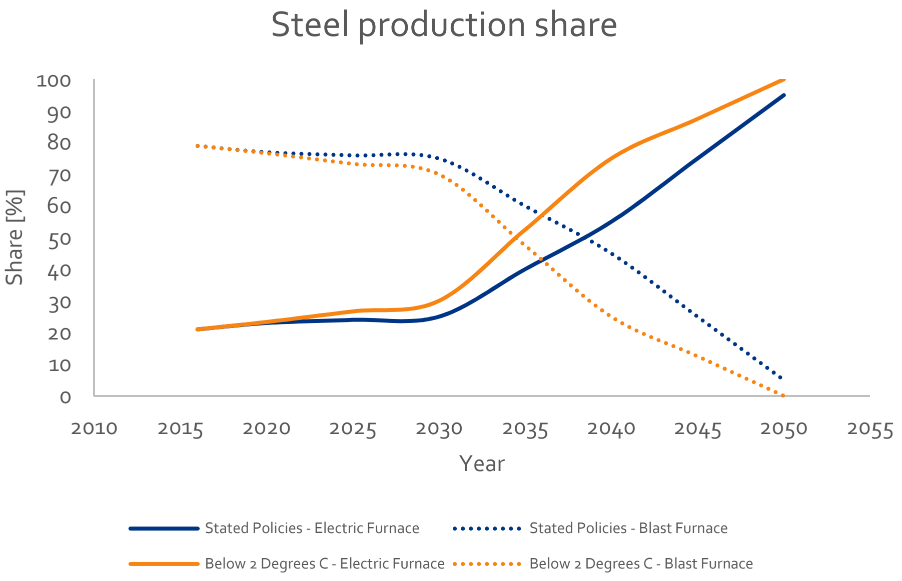
High energy-consuming industries including steel, cement, nonferrous and ferrous metal are hereinafter collectively referred to as Class I Industry and other industries are collectively referred to as Class II Industry in this model analysis. With future transformation towards light industry and high value-added industry, together with dwindling real estate investments and almost saturated market of infrastructure, the production of energy intensive heavy industry (other than chemical industry) in China is expected to decrease, and the demand for steel, cement and ferrous metal will slowly fall back to 40-80% of the current level. The forecasts on activity level of Class I Industry in different scenarios are shown in Figure 10-3.

Figure 10-3 Forecasts on activity level of class I industry (main high energy-consuming sectors) during 2015-2050



It is noteworthy that even though the production of most of high energy-consuming sectors is expected to decrease, their current energy consumption intensity and the utilisation of fossil fuels is still high. Taking steel industry as an example, the current production percentage of blast-furnace steel and electric-furnace steel is respectively 80% and 20%. Therefore, it is necessary to increase the electrification percentage of steel industry in addition to conventional means including system optimization and technical improvement, in order to improve the energy efficiency, reduce fossil fuel consumption and increase the proportion of renewable power in industrial energy consumption. The forecasts on the percentage of converter steel and electric steel in steel industry the two scenarios are illustrated in Figure 10-4.

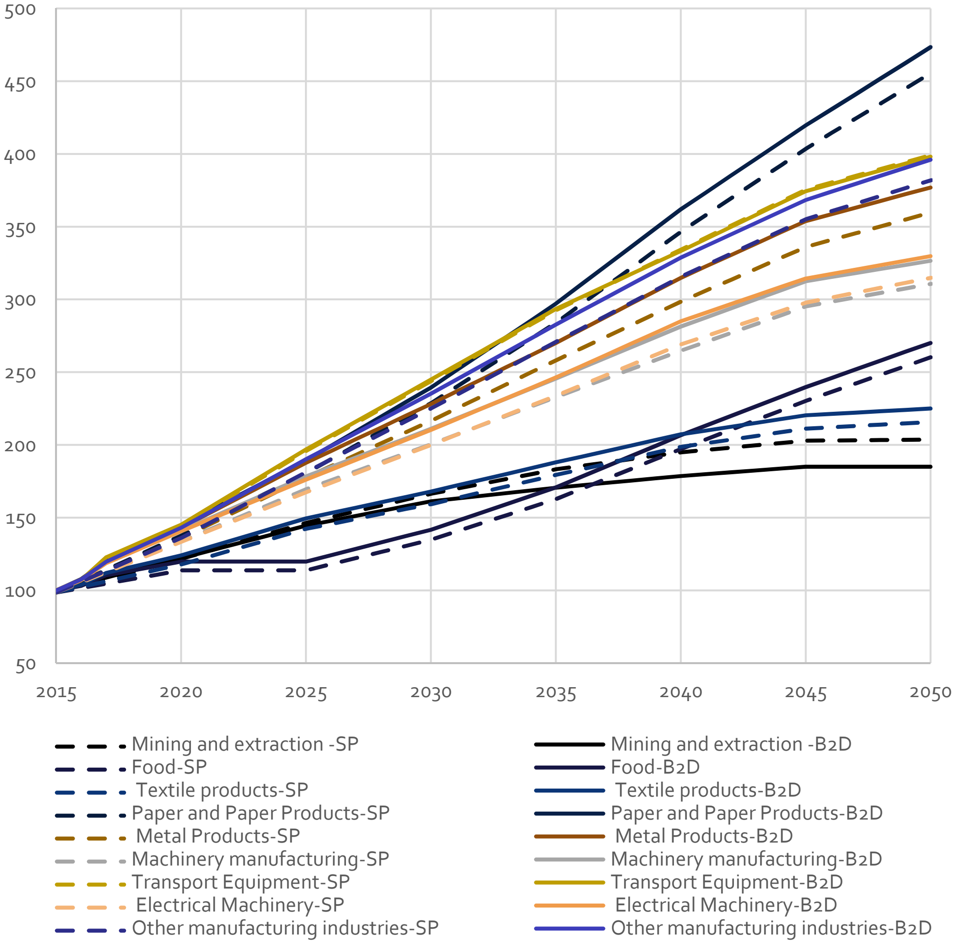
Figure 10-4 Share of converter steel and electric steel production during 2015-2050



The production of Class II Industry (other industries) has a larger difference compared with that of Class I Industry. Class II Industry in China is developing soundly with a large quantity of actors and has become globally leading over the past 10 years, whereby China has been labelled the "World's Factory".

Continuous innovation will be introduced in manufacturing technologies and production process for Class II industry (many of which take international market as the competition platform) in China, which will finally lead to high energy efficiency in industry. The final demand model forecasts that the added value of Class II Industry will be doubled to quintupled during 2015-2050 in two scenarios. The forecasts of economic activities in such manufacturing are shown in Figure 10-5.

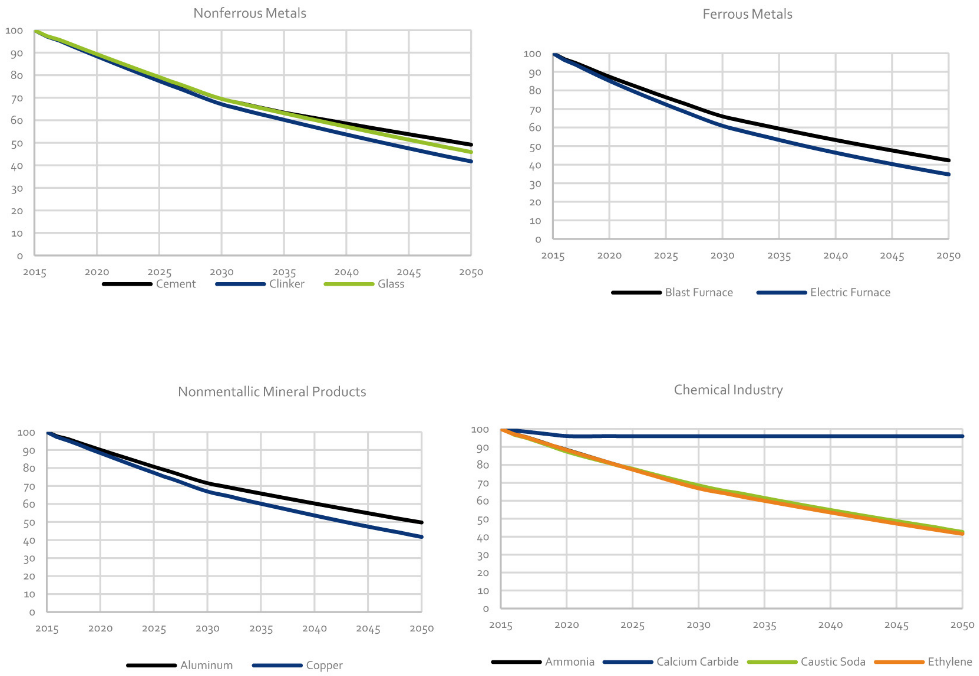
Figure 10-5 Forecasts on activity level of class II industry during 2015-2050



Technology industry progress and energy intensity change

Although China's energy intensity has been continuously and rapidly decreasing due to the industrial structural adjustment and technological progress, China's energy efficiency is still lower than the world's average. In 2015 the energy consumption per unit of GDP in China was 1.5 times of the world's average. However, with progress in supply-side structural reform and reinforcement of resource and environmental constraints in the future, more outdated, inefficient, high energy-consuming and high-emission capacity will be shut down and substituted, which will further drive the decrease in industrial energy intensity. The future energy intensity will be decreased to the same level in the two scenarios: By 2050, the energy intensity of heavy industry (Class I Industry) in China will be decreased to the level of OECD and EU25 in 2015, see forecasts on energy intensity level in Figure 10-6. The reduction of energy intensity of Class I Industry in 2050 will be more than 50% from the level in 2015.

Figure 10-6 Forecasts on energy intensity change of class I Industry during 2015-2050



It should be noted that, even with the projected declines in production and energy intensity, the Steel and Cement sectors both have high shares of the industrial sectors' energy consumption and use of fossil fuels. These sectors, further to electrification, must develop higher levels of energy efficiency using system optimisation and sustainable fuels. Western countries, especially in the Northern Europe, provide good examples showing us what measures could be introduced to production process in order to improve energy efficiency meanwhile reduce the emission. Two of the most ambitious examples are shown here, for Steel and Cement respectively.

Case study I-Strategies for increasing energy efficiency and optimising the use of blast furnace gas in steel production - Salzgitter Flachstahl GmbH.

As the largest affiliate of the Salzgitter AG group, the third biggest steel producer in Germany (2016), Salzgitter Flachstahl GmbH produces flat steel products, such as hot-rolled strip, cold-rolled sheet and surface-finished products, for vehicle manufacturers, tube manufacturers, construction industry, mechanical engineering and the domestic appliances industry. The company has been repeatedly acknowledged by the German Energy Agency (DENA) for its endeavours in the field of energy efficiency measures. This included winning the "Energy Efficiency Award" in 2013 and being awarded the "Best Practice Label" for energy-efficient pig iron production in 2014.

Efficient energy usage has been a key component of the corporate strategy of Salzgitter Flachstahl GmbH. The company initiated in 2009 a project with the objective of identifying potentials for savings and implementing efficiency measures in accordance with technical and economic considerations. A database of all individual measures was created to ensure employees always keep abreast of the project progress and be motivated to contribute their ideas for reducing energy consumption. By 2016, a total of 364 energy efficiency measures had been recorded in the database, with 215 of them being or going to be implemented. These range from replacing the hall heating controls in the cold-rolled sheet area to improving the heat recovery in high-temperature processes. In 2016, around 5560 employees produced approximately 4.6 million tons of crude steel and generated a turnover of € 2.2 billion. Productivity of the company (827.3 t /employee) is higher than the average productivity in the steel industry in Germany (495.3 crude steel/employee).

Major implementation examples of energy efficiency measures:

- Installation of a blast furnace gas expansion turbine
- Replacement of the hall heating controls in the cold-rolled sheet area
- Use of recuperators in high-temperature processes
- Modernisation of a blast furnace gas power plant
- Optimisation of system shut-downs during stoppages
- Demand-dependent operation of conveyors
- Installation of frequency converters for speed optimisation

Savings by efficiency measures:

Primary energy consumption for crude steel	
1990	21,3 GJ/t
2016	15,8 GJ/t
Reduction of energy consumption as result of energy efficiency	785
CO_2 reduction[3]	292.530
Reduction in energy costs[4]	€ 47.7
Investment	€ 287.2
Return on investment	17% p.a.

1 Figures are rounded.

2 Based on external electricity and natural gas purchases.

3 The calculation for natural gas (201.1 g CO2/kWh) and electricity (576.36 g CO2/kWh) is based on the Global Emission Model for Integrated Systems (GEMIS).

4 Assumed electricity price: € 0.096/kWh, assumed natural gas price: € 0.03/kWh.

Evaluation:

The company has implemented a total of 215 different energy efficiency measures, enabling it to achieve significant energy and cost savings as well as a clear reduction in

CO_2 emissions. Many of the measures are very innovative, such recuperative heat recovery in high-temperature processes, and can be adopted by other industrial companies.

A few of the measures, such as the optimization of the consumption of compressed air and the heating of production halls, are not just used in the steel industry, but can also be implemented in other processes and other branches of industry. The project has also demonstrated how important it is to involve employees in the identification of possible measures for optimization. The total effect of all energy efficiency measures was a reduction in energy consumption for flat steel production by 785 GWh.

For the cement sector, major innovations in energy efficiency and sustainability have been to utilise mid-temperature heat for waste heat district heating, while also utilising greener fuels for the kilns. Some advanced cement companies such as Aalborg Portland have made strides to implement innovations to deliver high-quality cement products to customers while also serving local community with cheap district heating in a sustainable manner now and in the future, as shown in the following case study.

Case study II-Danish cement factory Aalborg Portland has energy efficiency on the agenda

Large amounts of energy are required when producing cement. Danish cement production plant Aalborg Portland made an agreement with the Danish Energy Agency to conduct energy efficient measures to ensure a reduction of the energy consumption. This collaboration between private enterprise and government has brought large energy savings and at the same time it has reduced the plant's CO_2-emissions. CO_2 emission has been reduced with 21% over the last 30 years by using alternative fuels, optimizing the production and developing cement for climate friendly concrete products. The plant also supplies process waste heat to 23,500 households in Aalborg.

Energy management frames the effort

As a part of this agreement, Aalborg Portland has implemented the energy management standard ISO 50001 since 2003 and put energy management into practice in the production. The energy saving effort is organized so that the energy responsible employees report directly to the management of the plant. Together the energy management and the distinctive style of organization have led to a constant focus on energy and emission of CO_2 and NO_x as parameters of the plant's development – and have thus formed the basis for large energy efficient implementations and climate friendly product development at Aalborg Portland.

The plant makes waste useful

The plant has reduced CO2 emissions significantly by replacing fossil fuels with alternative fuels, which otherwise should have been deposited as industrial waste. The alternative fuels are partly "fluff" (contains 35 % biofuel), partly meat and bone meal as well as dried sewage sludge from the sewage treatment works of Aalborg municipality (100 % biofuel). Biofuel is neutral in the CO2 record.

An efficient production process

Besides the use of alternative fuels, Aalborg Portland also reuses the plant's own waste products in the production of new cement. A waste product is e.g. dust fractions from the flue gas emitted from the plant's flues or a flawed production of cement clinker. Instead of depositing it as waste, the far largest part is reused and utilized. The cement kilns constitute the core of production. Due to the high flue gas temperatures (1800-2000°C) in the kilns, the energy in the alternative fuels is utilized efficiently and there is no waste product left after incineration. Potential residuals simply melt and the ash residual is embedded in the cement clinker and thus becomes a part of the finished cement.

Cement and concrete of the future

Aalborg Portland also focuses on the development of new types of cement products that reduce the plant's CO2 emission. One step is the development of concrete products containing less cement. A large part of the CO2 emission from the cement production is due to the calcination of chalk, which takes place at high temperature where CO2 releases – so the less cement needed in the concrete, the less CO2 is emitted.

Supported by Innovation Fund Denmark project "Green conversion of cement and concrete production" (2014-2018), a new type of cement which needs less energy and emits less CO2 is currently tested in the first demo project--a bridge between Herning and Holstebro. Next the product will be tested in a busy road. The development of these new materials remains at an early stage, hence the actual possible CO2 reduction is yet to proven, but the hope is that a 30% reduction of CO2 emissions can be obtained in constructions of bridges and roads.

Waste heat for the city's inhabitants

Since 1988 Aalborg Portland has sold its waste heat to Aalborg City. The heat is extracted with heat exchangers from the flue gas of the cement kilns. Instead of the heat going out of the flues, it is used as district heating. 20-25 % of the fuel used at the plant in white cement production is thus of double use – first as fuel in the cement kiln and then as hot water for district heating purposes. Aalborg Portland is able to provide district heating to heat approximately 30,000 households.

Energy savings

Aalborg Portland's initiatives during recent years with extra focus on implementation of energy efficient measures in the existing production facilities has resulted in the implementation of projects from 2011 to 2016 ensuring energy savings in electricity and fuel at 258,000 MWh corresponding to the annual electricity consumption of approximately 65,000 households.

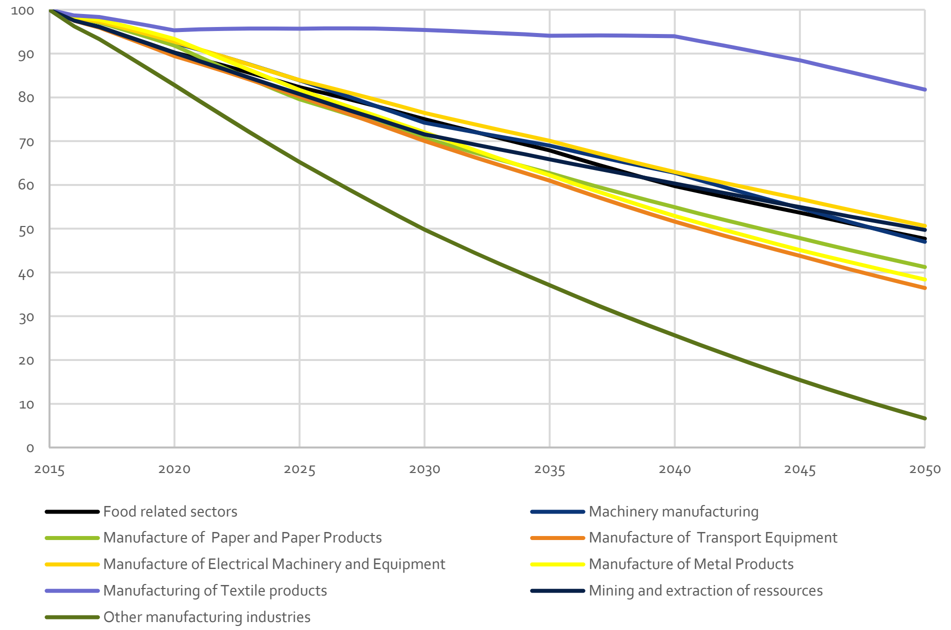
Aalborg Portland fact sheet:

- Employees: Approximately 261 at the plant in Aalborg.
- Annual turnover: Approximately 1.7 billion. DKK.
- Annually the plant in Aalborg produces 2.2 mill tonnes of cement. Maximum capacity is 2.8 mill tonnes of cement
- CO2-reduction from 1979 to 2016: From 1.18 to 0.93 tonnes CO2 per tonne cement
- The plant's energy consumption:
- Electricity: 292,000 MWh annually or 132.6 kWh per tonne cement
- Fuels (coal + alternative fuels) for the kilns: 438,000 tonnes or 3,200,000 MWh or 11,520,000 GJ annually
- CO2-emission: Approximately 2.0 mill tonnes CO2 annually

In the Below 2 °C scenario, energy efficiency measures similar to the European steel and cement cases are assumed implemented on a large scale in China. The scenario assumes the blast-furnace made Steel and the Cement sector moves towards these cases with completion already in 2035.

With respect to Class II Industry, China's energy intensity in 2050 will be decreased to be basically equivalent to that of EU25 for the time being and leading in the world. See Figure 10-7 for forecasts on the energy intensity level of industries.

Figure 10-7 Forecasts on energy intensity change of industries and sectors during 2015-2050



Energy technology and energy variety structure

The activity level and energy intensity of industrial sector are basically consistent in the two scenarios, while the Below 2°C Scenario has higher penetration variable renewable energy and higher degree of electrification, which are manifested by direct renewable heating or secondary energy (particularly power) supplied by renewables. Renewable energy utilised in heavy industry is mainly in the form of secondary energy, such as power and district heating, etc. As some renewable energy technologies, such as (non-concentrating) solar thermal heat, geothermal heat, and heat pumps, can only be used for low-temperature heating at present, the high temperature requirements of many industrial process heat applications, especially in high energy-consuming sectors, limit the potential application of renewable heat technologies, while these are already disseminated in the low-temperature domestic sector, such as food processing, printing and dyeing and textile. However, it should be noted that the energy technology application of industrial sector depends, to a large extent, on the technical route and process flow of specific industrial development stage. Generally, large scale direct application of renewable energy to industrial sector in near and medium-term is still restricted by technology and industrial development stage so that the application potential requires improvement in a longer term.

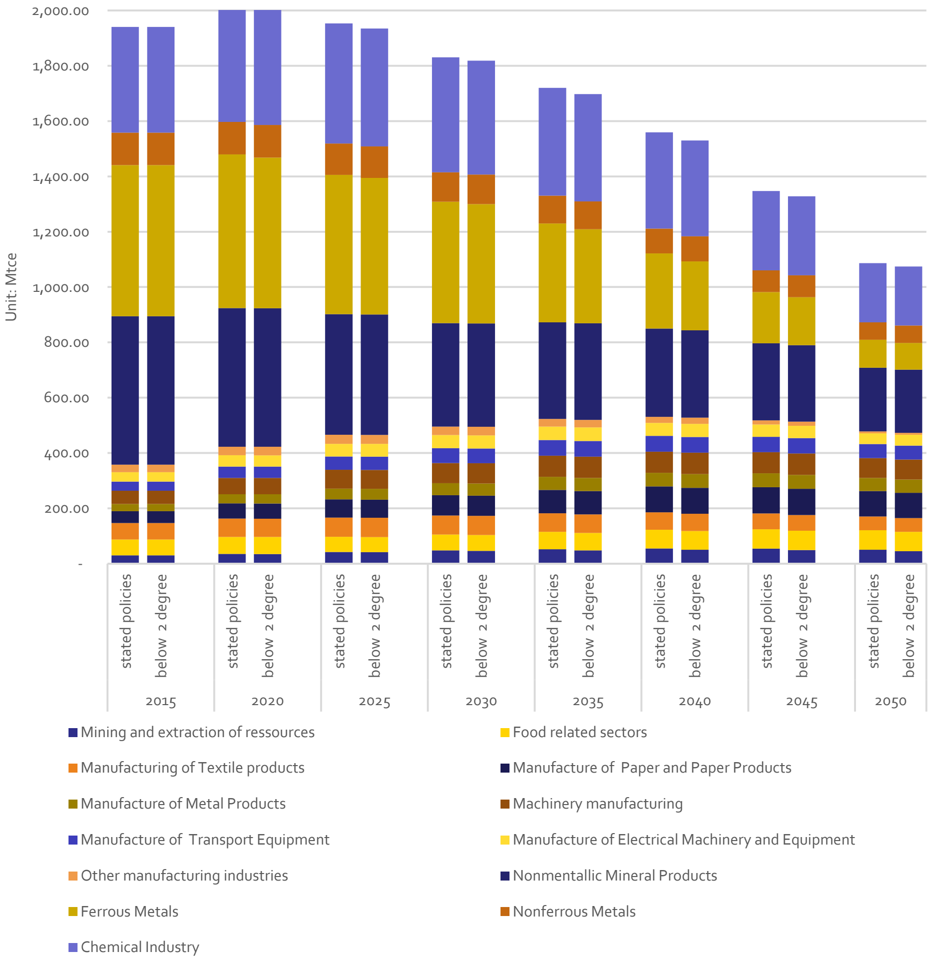
Final energy consumption of industrial sector

The CNREC END-USE Model analyses and calculates the final energy demand of industries regarding both fuel types and subsector demands based on the development of industrial sector, changes in energy intensity and the trend of energy variety structure adjustment as stated above.

In the Stated Policies scenario and Below 2°C scenario, the final energy consumption in industry is basically stable with slight decrease at the earlier stage. It then decreases to 1.83 billion tce and 1.82 billion tce respectively in 2030, and after 2030, decreases more rapidly to 1.09 billion tce and 1.07 billion tce in 2050 respectively in the two scenarios, due to accelerating progressive electrification, particularly in steel industry.

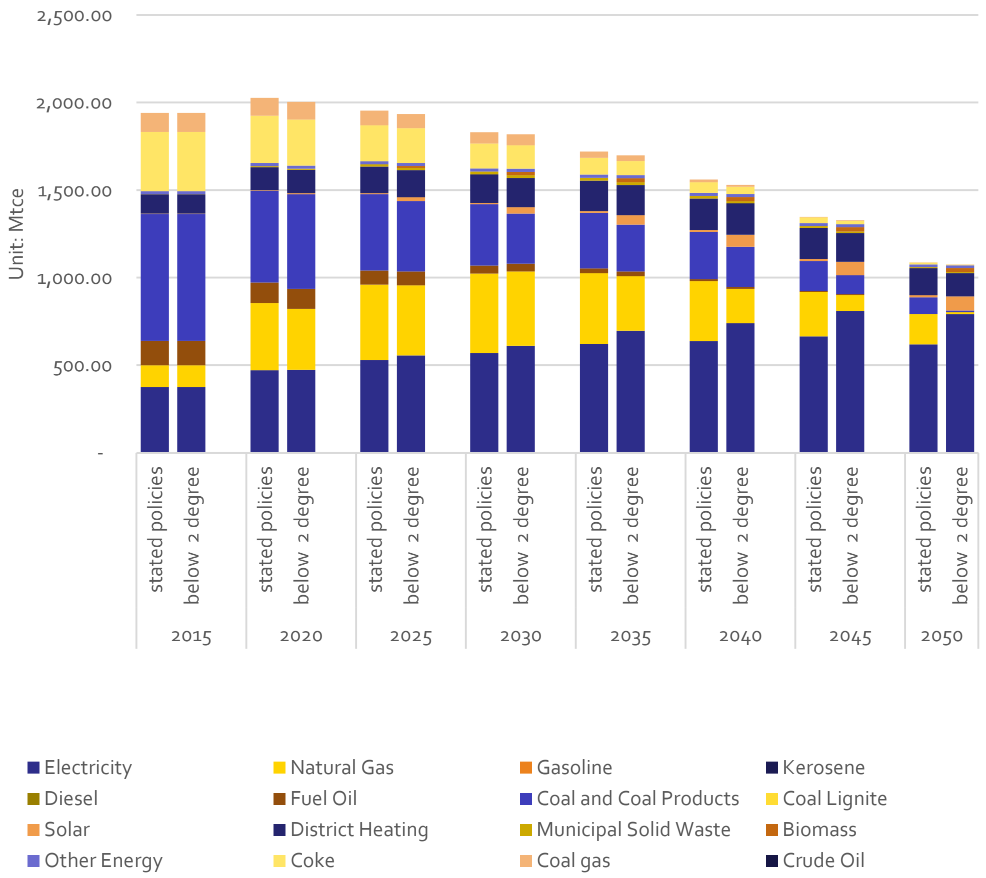
With respect to industrial structure, the energy consumption proportion of Class I Industry still dominates though slightly decreases. The proportion of manufacturing in industrial energy consumption is still low though with rapid development before 2030. The energy consumption of heavy industry is reduced more rapidly. Manufacturing still develops quickly during 2030~2050, and attains a proportion to the industrial energy consumption of approximately 50% in 2050.

Figure 10-8 ***Forecasts on Energy Consumption Structure of Industrial Sectors***



With respect to fuel type, there are significant changes in the fuel structures in both scenarios, while the overall trend shows that the consumption of oil (relatively expensive) and coal (heavily polluting) is reduced and a large quantity of natural gas and power are used. There is higher proportion of clean energy consumption and a lower coal consumption in the Below 2°C scenario. In the Below 2°C scenario, the power demand in 2050 is approximately 790 Mtce, being 2.1 times of that in 2015. The consumption of coal and coke is decreased by 98%, respectively decreasing to approximately 10 Mtce and 5 Mtce, with a total proportion of 1.3%, which nearly eliminates the use of coal. The scale of renewable energy heating and district heating will also be increased for 110%, reaching 250 Mtce in total. The demand of fuels during 2015-2050 in two scenarios is shown in Figure 10-9.

Figure 10-9 Forecasts on fuel structure of industrial final demand in Below 2°C Scenario during 2015-2050



10.3 Transport Sector

Status quo and trend of transportation energy

Transport is a fundamental sector of the economy, consuming considerable energy in the process of supporting economic development. Fast motorisation has been the biggest feature of China's transport transition since 2000. The automobile sales in 2016 reached 27.5 million and the total stock was over 194 million by the end of 2016. This is more than 10 times of that in 2000. China now has been the largest automobile market in the world with annual sales around 60% higher than in the United States. Energy consumption in transport has grown rapidly in China. According to NBS's annual statistics, the average growth of total energy consumption was 7.5% during 2000-2015, while transportation energy consumption had an average year-on-year growth rate of 8.6%. This is 1.14 times of the average growth rate of total energy consumption. Although the energy consumption of passenger transport has increased significantly over the last decade and is expected to continue to grow. Freight transport still accounts for a considerable share of the total energy consumption in transport sector. Petrol and diesel remains the main energy sources for transport, while kerosene, natural gas and electricity together only account for about 5% of transport energy use.

In the future, the main trend for the transport sector's change in energy structure change will be the substitution of petroleum products with electric drive and biofuel. In addition, natural gas and hybrid will occupy a certain market share. Currently, the gasoline internal combustion engine technology is the main bus application except for large busses in China. New energy busses mainly include BEV, internal combustion engine and natural gas vehicle and hybrid gasoline vehicle. As for freight vehicles, the diesel internal combustion engine vehicle technology is the current standard, and new energy vehicles are basically not in use.

In addition to the motorization, China's transport sector is also undergoing one of the fastest increases in electrification globally. According to the national target announced by the central government, China will promote 5 million new energy vehicles (NEV) by 2020 and the annual production of new energy vehicles will be over 3 million by 2025. There have been several policies released to accelerate the market growth of NEV. Financial incentives directed at electric car customers and users are essential for reducing the purchase cost and total cost of ownership gap between electric and conventional cars. Chinese electric vehicle customers currently enjoy one of highest subsidies in the world provided by both central and local governments. EV customers in seven Chinese major cities are also exempt from strict plate number restricts implemented on conventional petrol/diesel cars. In addition, the government further provides financial incentives for public investment in charging infrastructure development and allows operators charge extra fees on charger users. To address the shortage of the subsidy budget, the government is currently designing the EV production quota system and the associated credit market for automobile manufactures, where EV producers can benefit from credit trading with other ICE vehicle manufacturers. Thanks to the policies above, China is by far the largest electric car market with 336,000 new electric cars registered in 2016. Electric car sales in China were more than double the amount in the United States, where 2016 electric car registrations rebounded to 160,000 units. Including electric buses and various public service vehicles, the annual sales of NEVs in China was more than 500,000 in 2016 and the NEV stock has been over 1 million accounting for nearly 50% of global total.

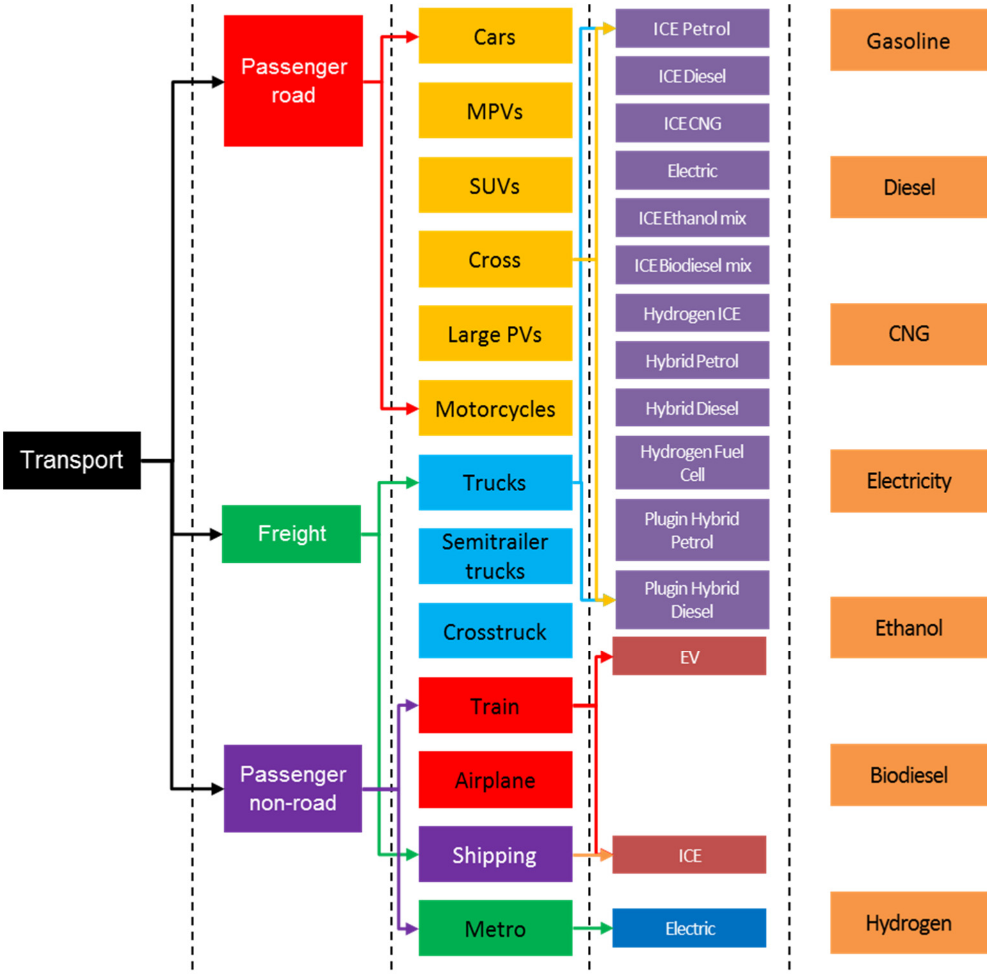
China's government is also curbing the development of conventional ICE vehicles. The State Council released "the catalogue of government approval investment projects" in 2016, which clarified that the government will not approve new ICE manufacturers and will also strictly limit manufacturing capacity expansion by existing manufacturers. Such policies reflect the government's decision of promoting NEV in the long term.

China is also the world's largest electric two/three wheelers market with estimated stock over 200 million units. Particularly in second/third tier cities, these electric two/three wheelers perform as an ideal transition for transport motorization. However, their long-term role is controversial due to safety, traffic and management difficulties. Since 2016 bicycles, integrated with cloud computing and smart phone services, are remerging in many Chinese cities as an effective solution for short distance travel. With the increase of public acceptance, these bicycles are expected to serve as an important option for "last mile" transport. However, given the limited range and weather/seasonal reasons, the development of bicycles is unlikely to significantly substitute the demand of automobiles in the long term.

Transport sector's final energy demand analysis framework

Figure 10-10 shows the final energy demand analysis model applicable to the transport sector.

Figure 10-10 Transport sector's final energy demand analysis framework



Road transport and vehicle sales change trend

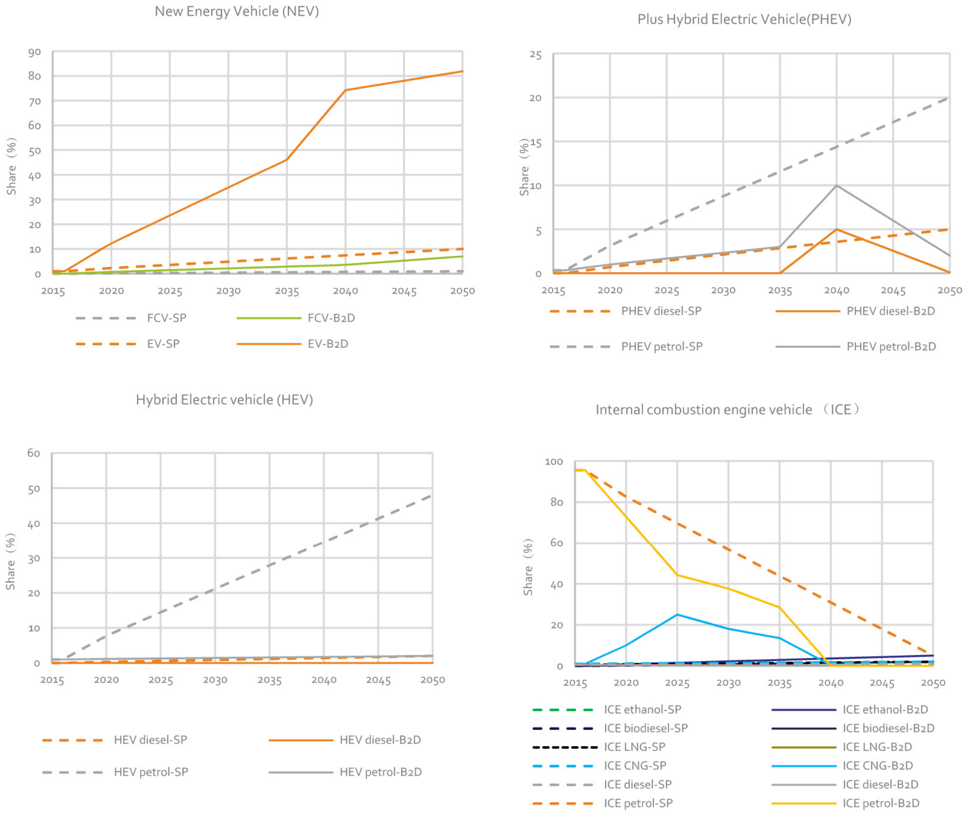
Vehicle ownership in China is about 143 vehicles per 1000 capita currently. In comparison with developed economies, where the figure is generally higher than 500, there is still a large market potential in China. The growth of driving intensity will increase the transport energy demand albeit to a minor degree. This study estimates the market potential of vehicle stock will reach 500 million by 2050 and the majority of the feet will still be passenger cars.

For EV development, this study applies the BASS diffusion model to forecast the electrification in the vehicle fleet. It consists of a simple differential equation that describes the process of how new products get adopted in a population. We derived the coefficients of innovation and imitation by fitting the historical data. For both scenarios, the overall transport demand will be same and the differences will be in terms of new technology penetration level and correspondent transport energy mix.

Under the Stated Policies scenario, the energy efficiency will be focused by future transport policies especially in road transport. It assumed that the efficiency of conventional ICE vehicles will be largely improved with the help of electric hybrid technologies and will be rapidly developed by 2030. The improvement of fuel efficiency will on the other hand accelerate the lifecycle cost reduction of ICE vehicles and eventually enhance their market share. The development of NEV will experience a linear growth profile under the scenario. As the financial incentives phased out form 2020, the market competition of NEV compared with ICE vehicles plays a decisive role. However, given the cost reduction of battery and fuel cell technology is slower than the expectation along with charging infrastructure development barriers, the market penetration of these new technologies is relatively insignificant (about 10% by 2050).

Under the Below 2°C scenario, the energy consumption and emission reduction will be largely driven by the introduction of NEVs. It is expected that NEVs will penetrate in passenger transport much faster than that in the Stated Policies scenario. The cost of both battery and fuel cell technology will drop significantly and electric vehicle will be more cost competitive than ICE vehicles in the market between 2025 and 2030. Given NEVs show more and more cost and performance advantages, it assumed ICE vehicles will fully phase out in the annual passenger vehicle around 2040, and the market shares of the NEVs will be linearly increased, and will become the leading technology of the vehicle sales market in 2050, with a market share of about 80%.

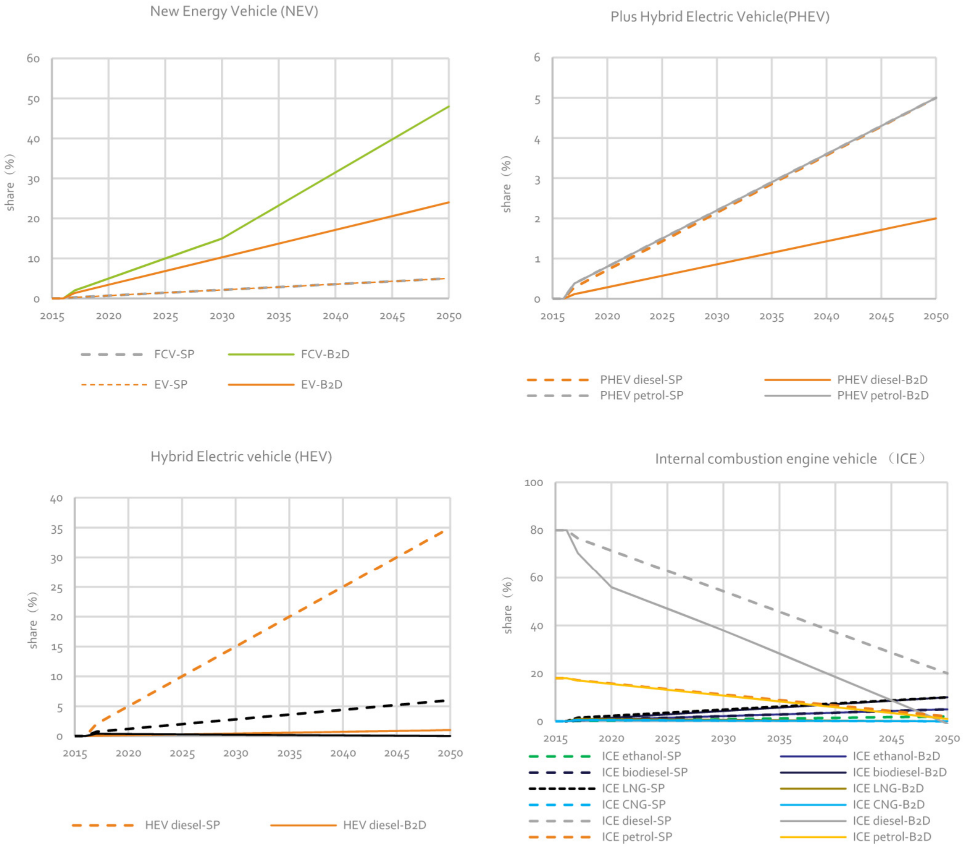
Figure 10-11 Technology proportion in annual sales of passenger vehicles



The transport demand and activity level are used to forecast the freight transport development. In the Stated Policies scenario, diesel will continuously dominate the fuel consumption especially for trucks. Biofuel consumption, including both biodiesel and ethanol, will grow over the next decades but at a minor rate if increase due to the resource and cost issues. Natural gas, on the contrary, is expected to satisfy a prominent marginal demand particularly in freight transport where NEVs face a higher market threshold. In the Below 2 °C scenario, CNG/LNG vehicles on the other hand will replace a much larger number of diesel vehicles than that in the Stated Policies scenario. The combination of natural gas and hybrid technology is expected to further reduce the energy consumption and emissions from freight transport. In summary, the transport electrification is slow in the Stated Policies scenario due to low market penetration of NEV in road transport. However, this does not mean the energy consumption and emission will increase continuously to 2050. The hybrid technology application in passenger vehicles plus the introduction of natural gas and biofuels in freight transport can also achieve a significant impact on the transport energy transition. It shows in Stated Policies scenario, the stock of vehicles will keep on growing mainly in passenger transport sector and reach 570 million in

2050. The population of hybrid vehicles including both hybrid petrol and diesel will take up nearly 40% of total vehicle stock. NEV will be only responsible for 25%.

Figure 10-12 Technology proportion in annual sales of freight vehicles



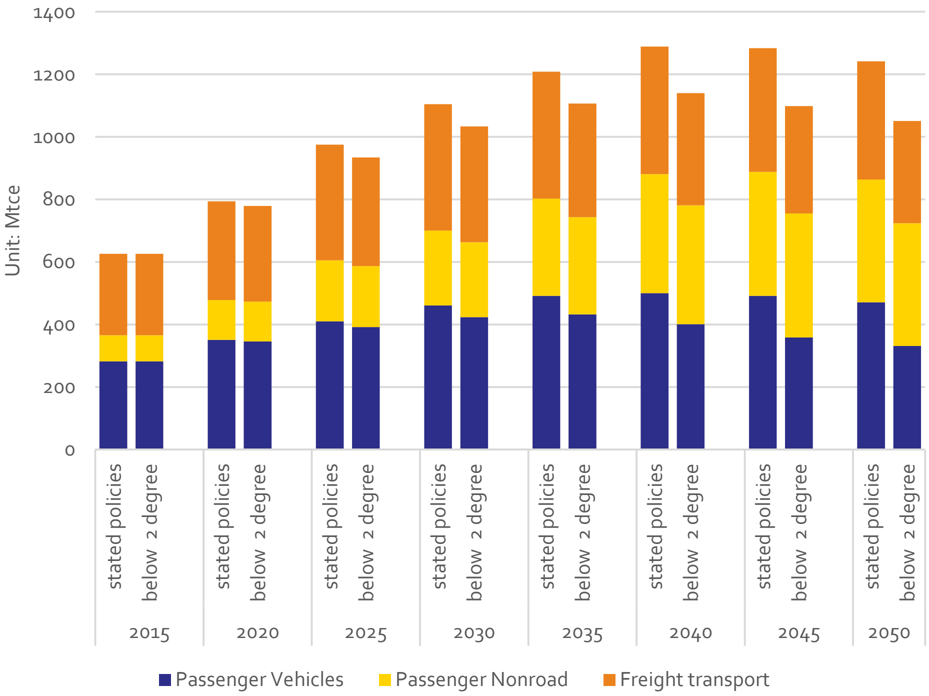
Non-road transport

Non-road transport includes aviation, ferry and track haulage. For freight transport, China's demand for non-road services is expected to rise under the influence of economic development. As industry activities have been widely developed, it is expected that the growth in the demand for freight services will be lower than economic development. During entire analysis, transport by electric train takes up the large part of rail transport. Only liquid fuel is used for ferry and aviation transport, and more attention is paid to hybrid technology, including biofuel.

Transport sector's final energy demand

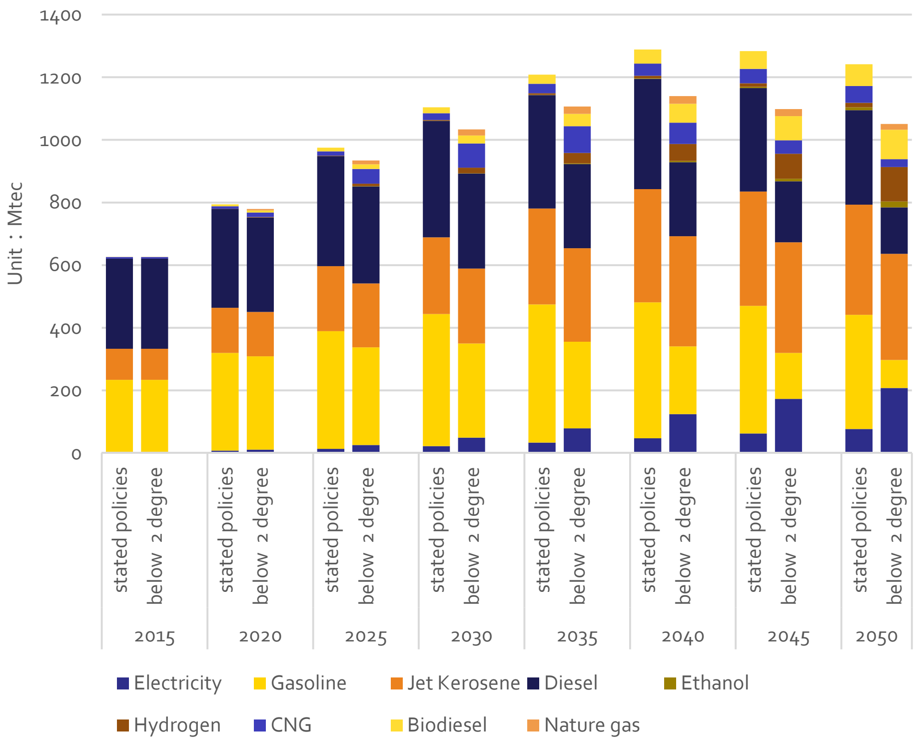
The energy consumption of the entire transport sector is calculated based on the above assumptions, and Figure 10-13 presents structure changes in transport sector's energy demand under different scenarios. By 2050, the energy demand differs much under Stated Policies scenario and Below 2°C scenario, being 1.24 billion tce and 1.05 billion tce respectively. Under the Stated Policies scenario, energy consumption for passenger transport and freight transport will simultaneously reach their peaks around 2040, about 500Mtce and 470 Mtce respectively. Under the Below 2°C scenario, energy consumption by passenger transport and freight transport will be 432 Mtce and 363 Mtce respectively by 2035.

Figure 10-13 Transport sector's final energy demand structure



As only for road transport, given the efficiency improvement of hybrid vehicles as well as the fast development of fuel cell, the NEV in the road transport sector will peak at 908 Mtce around 2040 and end in 849 Mtce in 2050 in the Stated Policies scenario, where electricity accounts for 7.8% of overall transport energy consumption. In the Below 2 °C scenario, due to the faster development of battery electric and fuel cell technologies, the electrification rate will reach nearly 30% in 2050 which is around 4 times the Stated Policies scenario. For the same reason, the peak of transport end use energy consumption will occur around 2035 with 795 Mtce. By 2050, the total transport energy consumption will decline to 658 Mtce, where electricity (including hydrogen) account for a much bigger share.

Figure 10-14 Fuel structure forecast of transport sector's final energy demand (including road transport and non-road transport)



10.4 Building Sector

Urbanization and energy consumption

Buildings is one of the key sectors determining whether China can achieve its energy transition from fossil fuel to a sustainable system with high penetration of renewables. In America and Europe, energy consumed by buildings accounts for 40% of total energy consumption, while currently 25-30% in China. However, with continuing economic growth, urbanization and increasing attention to indoor living conditions, China's energy demand for buildings is increasing. With increased affluence will come a rising demand for comfort which increases building energy services per unit of floor space, as well as the expansion of building floor space. From 1980 to 2015, China's urbanization rate had been elevated from 20% to 56.1%. In this research, we project the urbanization rate will rise from 56% in 2015 to 68% by 2030 and 78% by 2050. The average floor space per capita for urban and rural area is 33m^2 and 35m^2 respectively, and is expected to rise to 40m^2 and 45m^2 by 2050 respectively. By 2050, the total floor area will reach 83 billion m², including 60 billion m² residential buildings and 23 billion m² commercial buildings.

Table 10-1 China's population, urbanization and floor space

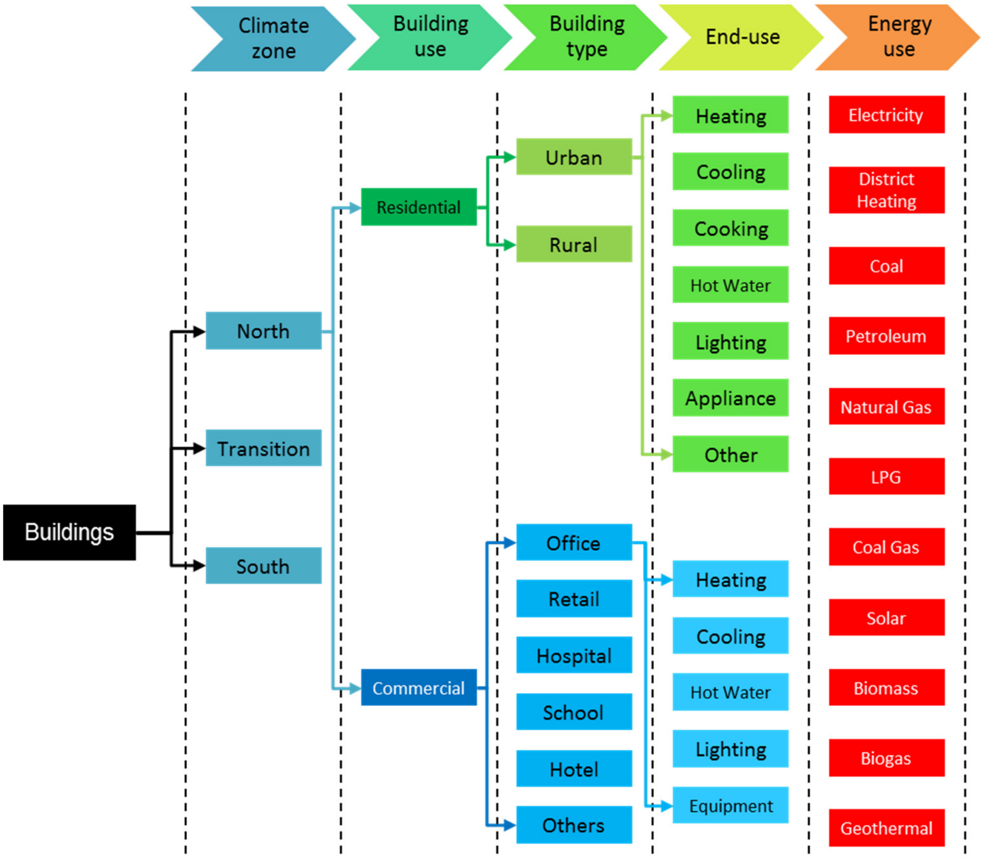
	2015	*2020*	*2030*	*2040*	*2050*
Population (million)	1,383	1,429	1,503	1,439	1,380
Urbanization rate (%)	56	60	68	74	78
Urban housing area (M² per capita)	33	34	36	38	40
Rural housing area (M² per capita)	35	37	40	42	45
Residential floor area (billion M²)	47	52	56	59	60
Commercial floor area (billion M²)	16	18	23	24	23

Due to incomplete electricity access in rural area and low indoor thermal comfort standards for residents and commercial buildings, and energy consumption intensity of the China's building sector is obviously lower than that in the developed countries. However, along with the burgeoning middle class, who are typically urban living families that require modern amenities and equipment, the final energy service, such as heating, refrigeration, ventilation, lighting, household appliances and office facilities, will continuous grow. As long as the growing desire for comfortable life and the continuing activities of modern business, there is no reason to believe that China's building energy growth will wane anytime soon.

Final energy demand analysis framework in building sector

CNREC END-USE analyses energy consumption in building sector according to climatic diversity, building types and energy services. Firstly, the locations of buildings in China may be divided into three key climate zones, including North China (severe cold and cold regions), transition zone (hot summer and cold winter zone) and South China (hot summer, warm winter and temperate region). In each climate zone, the buildings may be further divided according to their types and functions (residential and commercial building). For various types of buildings, we have further built energy end-use model, which identified typical energy service in buildings, including heating, refrigeration, cooking, hot water, lighting, household appliances and other purposes. Finally, different final energy use technologies and fuels are related to each end-use energy service of particular building type cf. Figure 10-15.

Figure 10-15 Construction sector's final energy demand model framework



Building energy use technology

Residential building energy demand mainly includes heating, cooking and electrical appliances. Residential electricity is mainly consumed for cooking, air conditioners and electrical appliances. Energy consumption by refrigeration and ventilation in China's residential buildings will significantly rise in the future, with reference to the high energy consumption by building ventilation and refrigeration in developed countries, as the residents have higher requirements for comfort of residential environment. Currently, such daily household appliances as refrigerators, washing machines and TV sets have been popularised among China's urban and rural residents. In the future, computers and other household appliances will be further popularised. District heating, advanced energy saving and isolation technology will be applied in public buildings in a large scale, and the building energy saving rate will gradually increase. The energy intensity for building heating will continuously decrease, and district heating and central air conditioners (or heat pump) will mainly be applied in large public buildings.

Using renewable energy for heating has a huge potential in the buildings. Globally, renewable heating accounts for 25% of total heating demand, with 2/3 of renewable energy is biomass. In China's rural areas, biomass is widely applied for heating, hot water and cooking. However, energy efficiency of the biomass furnaces is very low, and air pollutants will be inevitably generated. Modern biomass application technology include biomass based CHP and biomass boilers. Regarding solar thermal energy application, China is ranked the top in the world, and the large-scale solar energy system has been applied in district heating. In recent years, the large comprehensive solar energy system which satisfy the demand for space heating, cooling and hot water for residential buildings, public buildings and industrial applications have become a new trend. At the time of keeping and even increasing the heating by centralized air conditioning system (heat pump), fossil fuel is substituted with solar energy, biomass energy, geothermal energy and other renewable energy sources for district heating in a large scale. In Europe, solar thermal energy and biomass/natural gas combined systems can meet the demand for 100% of hot water and 15-30% of space heating. In the future, large centralized and hybrid solar thermal system will be commonly used to more efficiently utilize solar energy. Geothermal energy technology includes direct use and ground source heat pump. The ground source heat pump has a very high energy efficiency compared with heat-only boilers, with energy consumption reduced by 30% compared with natural gas boilers and 60% compared with coal fired boilers. The operating cost of the ground source heat pump technology is 40-60% less than conventional air conditioners in summer.

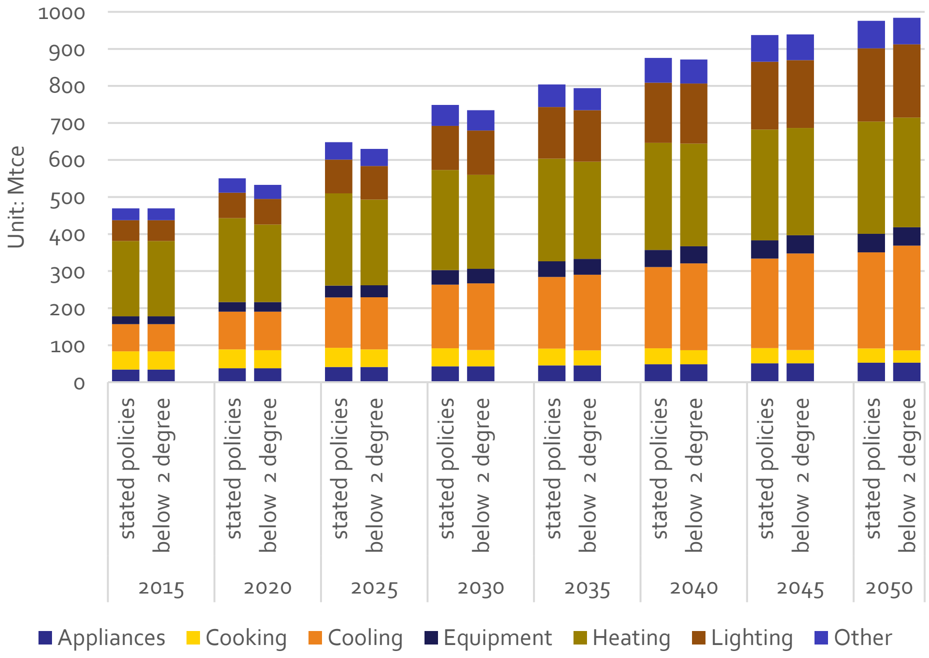
Table 10-2 Building-related renewable energy technology and application type

	Renewable energy technology	*Direct heating*	*Refrigeration*	*Electricity*
Solar energy	*Solar thermal energy (space heating and hot water)*	X	X	
	Solar photovoltaic			X
	Solar heating and cooling	X	X	X
Geothermal	*Deep-high temperature*	X		X
	Deep-low temperature	X	X	
	Shallow-low temperature	X	X	
Biomass	*Boiler*	X		
	CHP	X		X
	Combined heating & cooling and electricity	X	X	X
	Municipal solid waste incineration	X		X
	Biogas	X		X
Electricity	*Electric boiler*	X		
	Heat pump	X	X	

Building sector's final energy demand

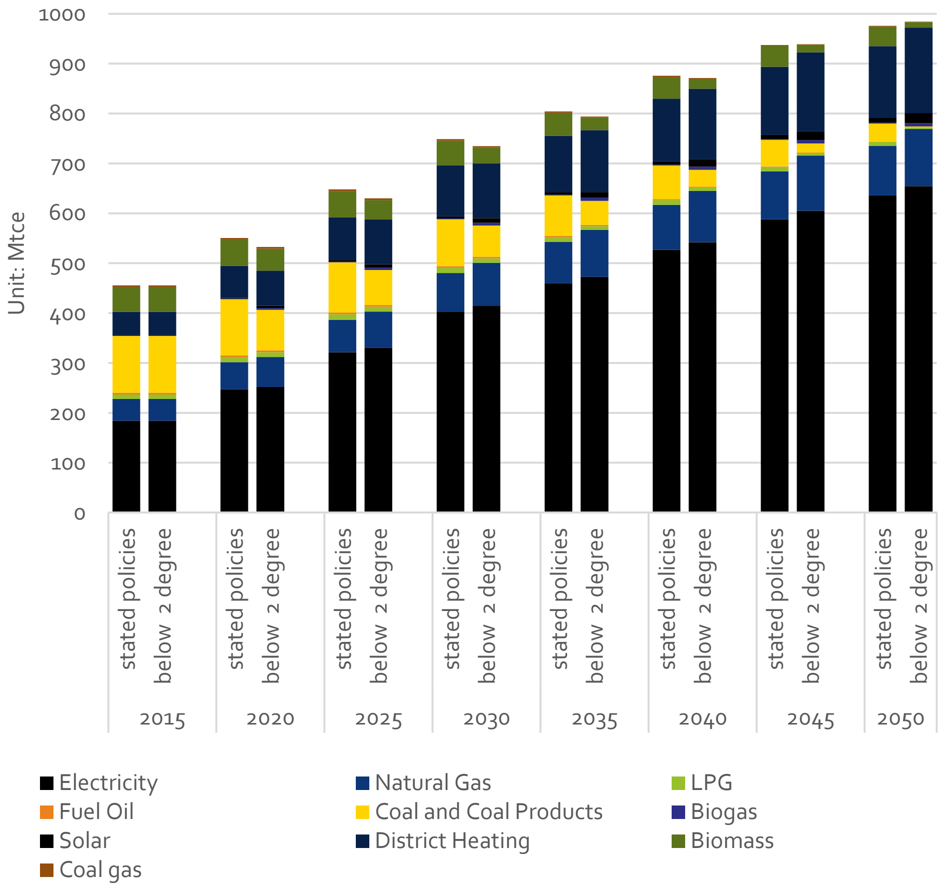
According to scenario analysis of above models, as the population further increases and urbanization is continuously promoted, the building as the main space for working, living and leisure will consume more energy. Under the Stated Policies scenario and Below 2°C scenario, the building sector's final energy demand will reach 976 Mtce and 984 Mtce respectively by 2050, and final energy will be mainly used for heating, cooling and various types of electrical equipment. As a large quantity of electricity energy and renewable energy are consumed, various types of renewable energy will be developed and utilized to the greatest extent.

Figure 10-16 Energy consumption of various activities of buildings sector



Fuel mix for energy consumption by the building sector is not very different under the two scenarios, but in both scenarios the fuel mix is improved by 2050. Under the Below 2°C scenario, coal consumption stagnates and starts to drop, and the consumption will decline to 1.3% of that in 2015 by 2050. Electricity consumption continuously and rapidly increase to 5,300 TWh (654 Mtce), which is 3.6 times of that in 2015. Natural gas consumption will steadily increase to 115 Mtce, which is 2.6 times of that in 2015. District heating, biomass, solar energy, geothermal heating and other renewable energy sources together will be increased to 210 Mtce by 2050.

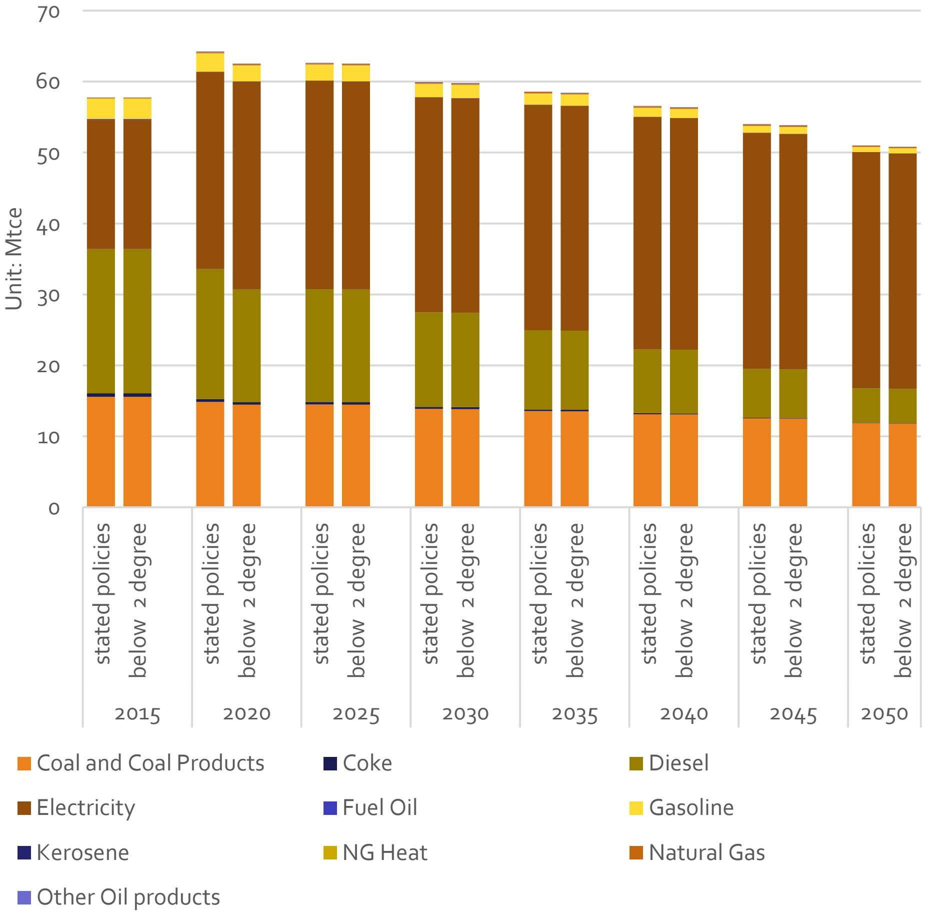
Figure 10-17 Buildings sector's final energy consumption structure



10.5 Agriculture and Construction Sector

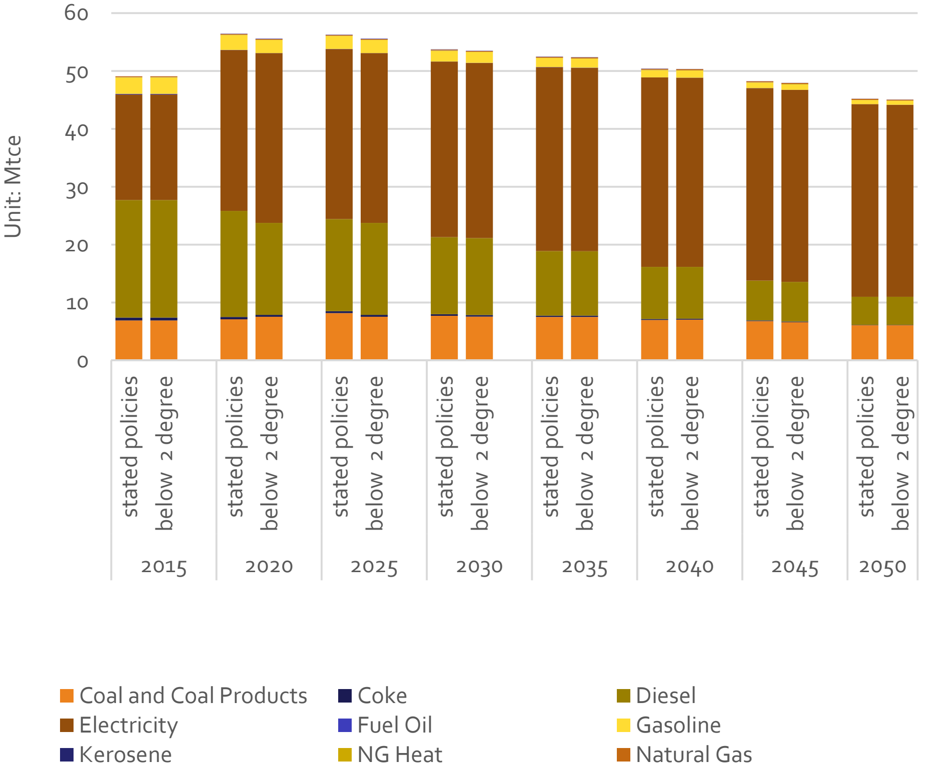
China yet to realise agriculture modernisation, which is expected to be enhanced in the next twenty years by more intensive farming. Driven by agriculture modernisation, farm mechanisation and electrification will be applied on so large a scale that the agriculture sector's energy structure will be significantly adjusted. The key is to control final coal consumption, and coal consumption will gradually drop. However, in consideration of the improvement of fuel oil efficiency and electricity substitution, consumption of petroleum products will have a huge potential for substitution and reduction. Electricity consumption will steadily grow with the increase of agricultural mechanization and electrification. In total, it is expected that the total final energy consumption by the agricultural sector will maintain a stable level, and there is little difference under the two scenarios (about 51 Mtce by 2050), but the proportion of electricity consumption will be increased from 32% in 2015 to 65%.

Figure 10-18 Agricultural sector's final energy consumption scenario analysis



China has entered the middle and later stages of urbanisation, and energy consumption of the construction industry has basically reached the peak (here the construction refers to the activity or process of constructing a building or infrastructure). Energy structure will be adjusted along with the prevalence of low-carbon buildings and more energy-efficient engineering technologies in the future, to reduce the consumption of fuel oil and coal and increase the share of clean electricity in the total energy consumption. It is expected that the construction sector will consume 41.86 Mtce by 2050 in both scenarios, mainly fuel oil and electricity consumption.

Figure 10-19 Construction sector's final energy consumption structure

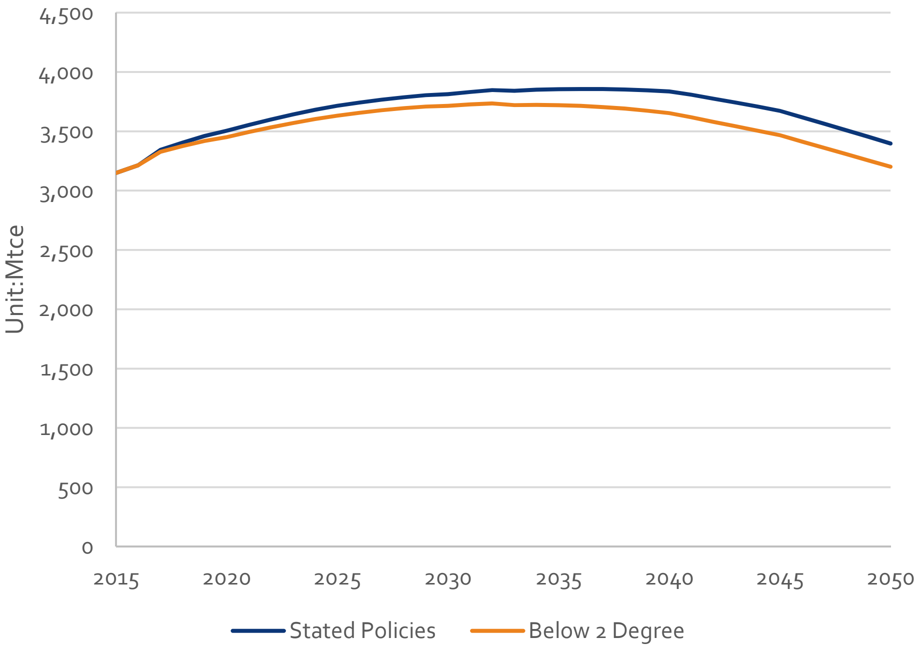


10.6 Total Final Energy Demand

Driven by more and more economic activities and improvement of people's living standards, China's final energy demand in the scenarios will peak in 2030-2035 and then decline due to energy efficiency measures. The application of energy efficiency, renewable energy and the industries-to-services transition, however, decouples the economy from the CO_2 emissions and energy use. The Chinese energy system in 2050 will be cleaner, more energy efficient and greener.

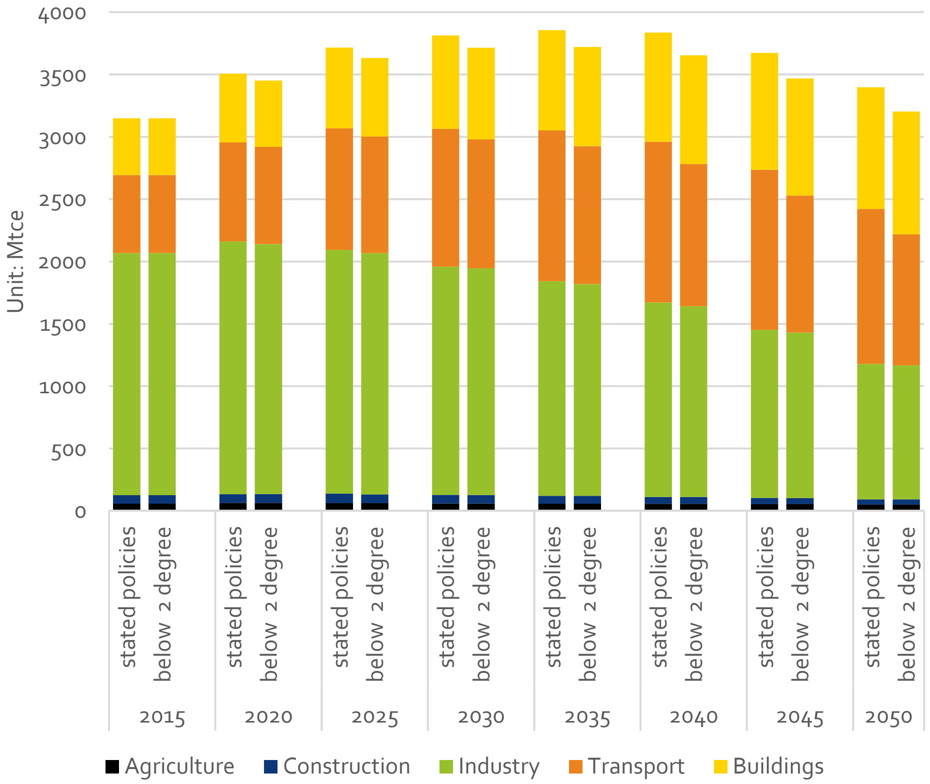
The energy end-use develops similarly in 2015-2050 in the two scenarios, as they assume similar implementation of energy efficiency measures. The economic development causes the energy demand in several sectors to increase, such as buildings, fulfilling especially increased demand for modern services and advanced products. The utilisation of energy efficient technologies and increased use of secondary fuels like district heating and electricity causes the final energy demand to peak already in 2036 (at about 3,856Mtce) and 2032 (at about 3,734Mtce) for the Stated Policies and the Below 2°C scenario, respectively. If China continues according to the Stated Policies scenario, its 2050 energy demand is 8% higher than 2015, about 3,397Mtce, only 2% than 2015. If the more ambitious policies from the Below 2°C scenario are implemented, the final energy consumption will be around 3,202Mtce in 2050, as shown in Figure 10-20.

Figure 10-20 Final Energy Demand under Different Scenarios in 2015-2050



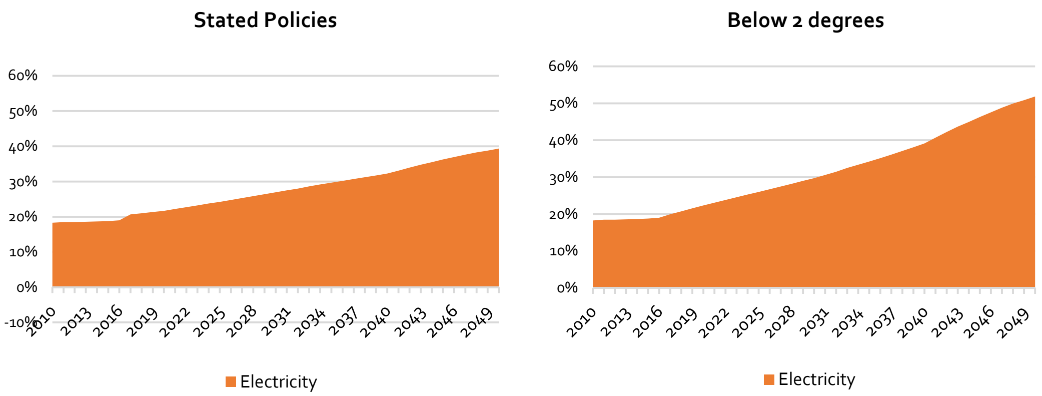
By 2050, China is seeing a momentous shift in its energy demand between uses, with heavy industries slowly losing their role as the most energy consuming sectors, in favour of private services, such as building energy use and transportation. The share of industrial energy consumption will be decreased from 62% at present to 32-34%. The building sector's energy consumption will be increased from 14% to 29-31%, while the transport sector's energy consumption will be increased from 20% to 33-37%. Transport sector will become the largest of the five sectors, as shown in Figure 10-21.

Figure 10-21 Final energy demand by sector in 2015-2050



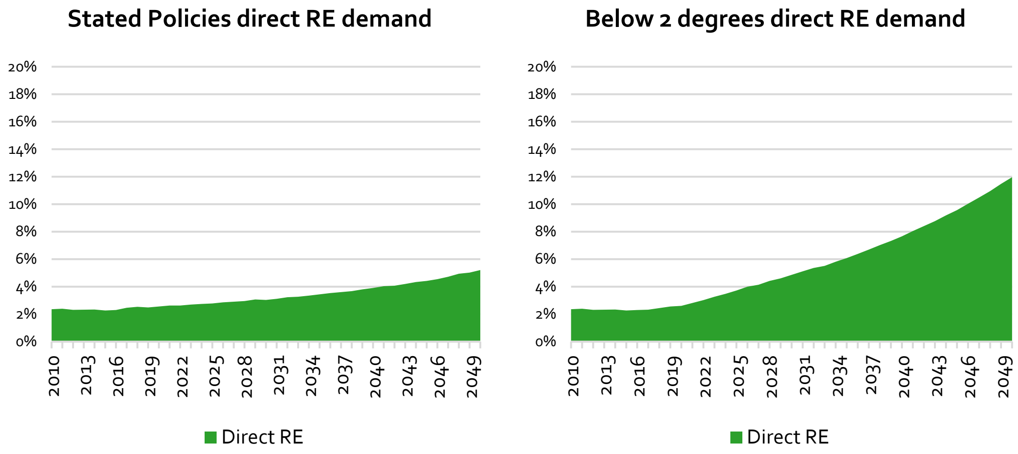
Both scenarios continue the emphasis on transitioning the use of fossils at the end-use by increasing electrification. Electricity accounted for 19% of the fuel use in 2016. The Stated Policies scenario increases this to 40.8% (11,270 TWh) in 2050, while the more ambitious Below 2 °C scenario increases electrification to 53.3% (13,9000 TWh), making electricity the dominant energy carrier for to satisfy final energy demand in both scenarios. Electric technologies have higher energy efficiency at the end-use point than similar fossil technologies, meaning the increase in electrification displaces more fossil fuels, and thereby local pollution and emissions, than the percentage increase itself. To avoid emissions at the transformation point, the increased electrification should be balanced with high utilisation of renewable produced electricity, as described in detail in Chapter 11.

Figure 10-22 Electrification 2010-2050



The utilisation of direct renewables has been limited in China so far, with most of the investment in renewables focused on producing green electricity. While these investments continue, there will be increased development in direct RE. Direct RE represented 2% of the fuel uses in 2016, including biofuels. In the Stated Policies scenario, this increases to 5% for 2050. For the same year, the use increases to almost 12% in the Below 2 °C scenario.

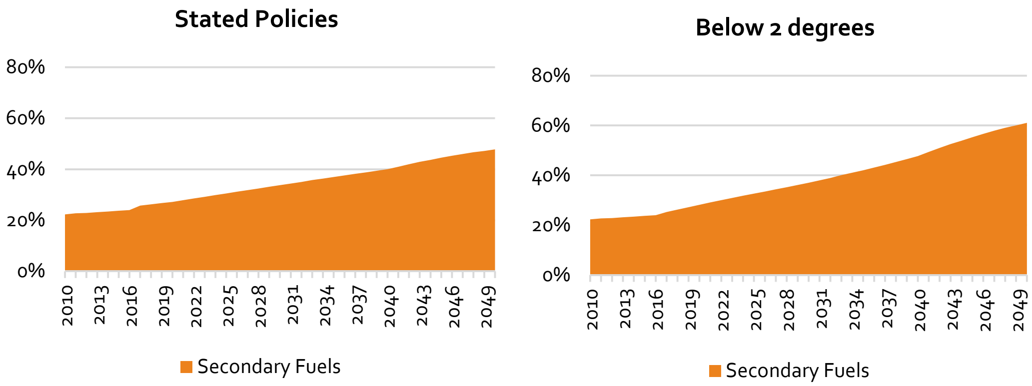
Figure 10-23 Direct RE demand 2010-2050



demand side, while increasing efficiency and renewable energy proportion of these secondary fuels. Most of this secondary energy is electricity, district heating and hydrogen.

These secondary fuels represented 24% of the total end-use energy demand in 2016. All secondary fuels increase, fulfilling 50% and 63% of the end-use demand in 2050 in the Stated Policies and Below 2 °C scenarios, respectively.

Figure 10-24 Secondary fuel demands 2010-2050



The increase of these energy carriers is dominated by electrification, but also district heating has increased utilisation. Like electricity, its higher end-use efficiency means it displaces more fossil fuels than the end-use demand shows.

As for the share of end-users heating in the total final energy demand, direct RE for heating grows from 1% in 2015 to 1.7% (1.15% for residents, 0.55% for industry) in the Stated Policies scenario and to 4.4% in the Below 2 °C scenario (1% for residents, 3.4% for industry). District heating grows from 5% in 2015 to a little less than 9% in the Stated Policies scenario in 2050. Below 2 °C scenario projects the district heating utilisation to be slightly above 9%, with more district heating used in buildings. A large share of the district heating is coproduced with electricity through CHP, ensuring high primary efficiency. Electricity demand for residential heating in both scenarios are almost the same, about 2%.

As the consumption of both direct renewables and secondary fuels increases in China towards 2050, the fossil fuel consumption in the end use sectors decrease. Coal already peaked in 2013. Natural gas has a large role in displacing local coal and coke use, but peaks in 2030. Oil products are still in wide utilisation, as transportation sector dependencies last far into the projection period.

Figure 10-25 Major fuels demand demands 2010-2050

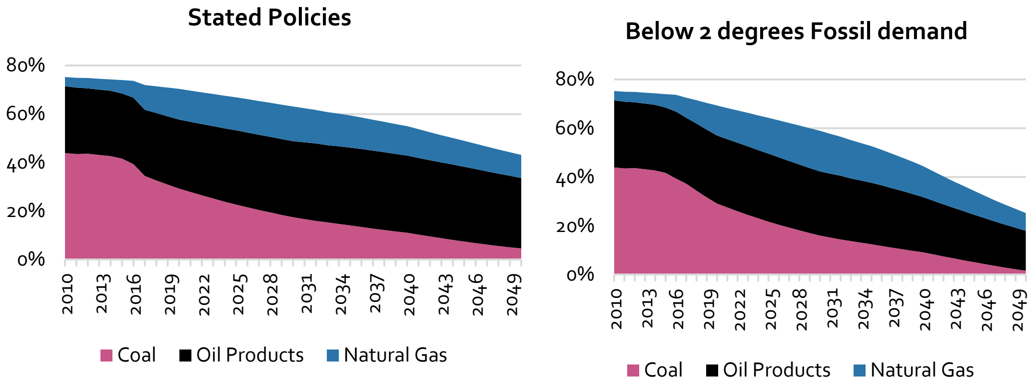
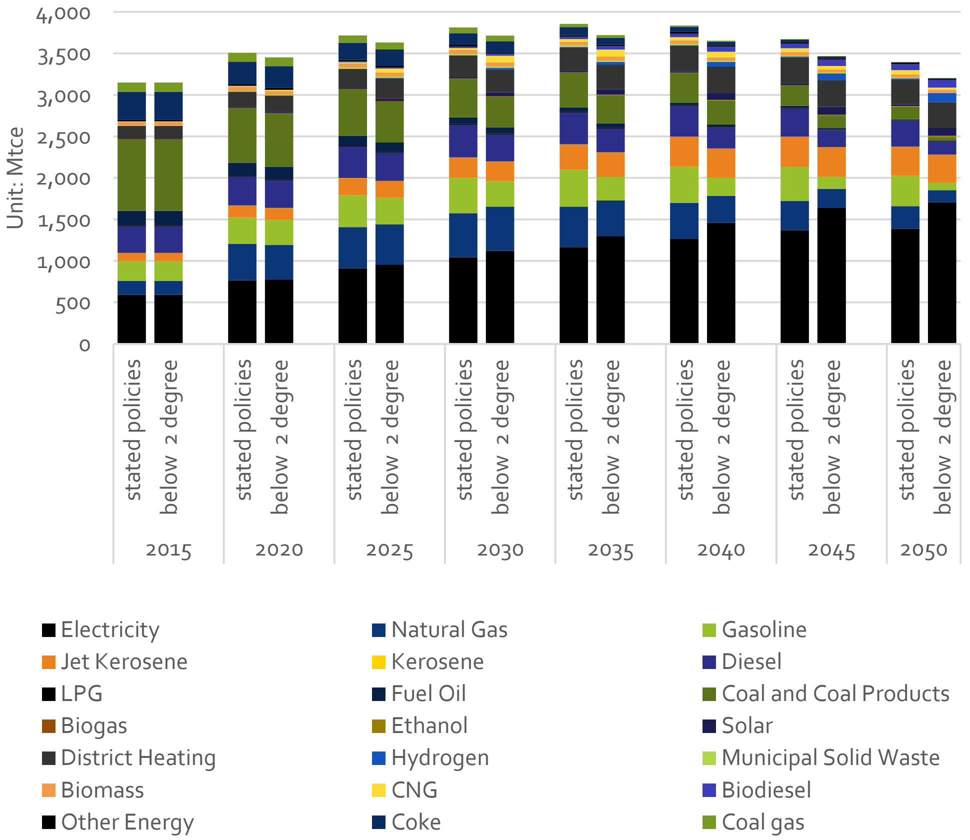


Table 10-3 Share changes for fossil fuels

FUEL	*PEAK YEAR STATED POLICIES*	*PEAK YEAR BELOW 2 °C*	*STATED POLICIES SHARE 2050*	*BELOW 2 °C 2050 SHARE*
COAL PRODUCTS	2013	2013	4.8%	1.1%
NATURAL GAS	2030	2030	9.7%	5.3%
OIL PRODUCTS	2039	2025	31%	18.8%

The final energy mix for the end-use energy demand shows how electricity, district heating and direct RE replaces fossil fuel use, while the overall energy demand peaks and then declines.

Figure 10-26 Final energy mix 2015-2050



11 Power sector outlook

This chapter details the main scenario results for the power system. The emphasis is the development at a system level. The chapter is structured such that four sections successively describe the evolution of the power system in terms of:

- Power generation and capacity (Section 11.2)
- Power consumption (Section 11.3)
- Power grid development and transmission flow patterns (Section 11.4)
- Deployment and utilisation of electricity storage (Section 11.5)

These four parts describe the power system transformation in the two scenarios in terms of annual values the physical structure of the power system. Following this, Section 11.6 provides a deep dive into how the system described in the previous section is operated, by looking specifically at how aforementioned four power system components work together to ensure that there is always a balanced between supply and demand in the power system. In this section, the evolution is described first by looking national level hourly supply and demand situation. Subsequently, to ensure that the role of transmission grids in the system balancing is covered, a single province (Guangdong) is selected to illustrate how the local generation, storage and consumption, interacts with transmission options to and from other provinces power systems.

While this chapter describes the physical developments in terms of MW's and MWh's, other impacts of the power system's evolution in the scenarios, has been described in the context of the overall energy systems transformation in Chapter 9. Additionally, the implication of the transformation in terms in relation to institutional frameworks, market design and supporting policies, is dealt with Part 3 of this report.

Naturally, this chapter includes a fair amount of details on the role taken by individual technologies, in context of their overall contribution to the power system. Further details of the specific power technologies resource potential, cost development, sub technologies and deployment patterns, are included in the Chapter 13 for RE technologies and Chapter 14 for fossil fuel-fired technologies.

While many assumptions are included in in each of the sections in the following, the main assumptions have been introduced in Chapter 8, and are therefore not repeated in this Chapter. The Chapter is concluded with a short summary (Section 11.7).

Following this introduction, the Chapter commences with a summary of the key aspects of the power systems energy transformation.

11.1 Main aspects of the power system transformation

While the two scenarios are expressions of alternative pathways and paces for China's energy transition, the implication in terms of the transition of power system operations and the future requirements tell a consistent story.

Firstly, coal plays a new role in the power system. The historical role of coal as the crux of the power system will end in both scenarios. There is a residual role in the long-term, but more importantly a transitional role in providing flexibility and stabilizing inertia to the power system. This is especially important while other power generation and storage solutions are being designed, demonstrated, distributed, deployed and scaled up.

Secondly, wind and solar take lead. As the demand for renewable energy, CO2-emissions reductions and clean energy increases. These technologies drive the supply side of the transition in the power sector and share characteristics with defining impact on the redesign of the power system. Wind and solar resources are specific with respect to location and timing of generation. While able to deliver on the promise of abundant low cost clean electricity, they stimulate increased demand for flexibility from all the other components on the supply and demand-side, as well as for transmission capacity and operational flexibility.

Thirdly, limited biomass resources are used in the power sector. Biomass power generation plays a role in the power generation mix, but biomass resources in China are comparatively limited. In the scenarios, a significant proportion of these resources are diverted away from the power sector to decarbonise other uses of energy.

Fourthly, supply and demand are balanced in a new way. The significant displacement of traditional dispatchable generation and the large proportion of electricity generation coming from VRE sources instigates a paradigm shift in how the demand and supply balance shall be maintained in the power system. The role of the demand side response increases both through including demand side flexibility in traditional power loads as well as ensuring that the conjunction with increased electrification creates further flexibility in the power system.

Fifthly, electric vehicles can play an important role. The implication of a vast deployment of electric vehicles can present a challenge to the system operation, not to mention challenges on the distribution side, an aspect that has not been considered in this analysis. However, if the market framework and incentives are established, the inherent flexibility between time of charging and time of use can benefit the power system. In these simulations, the vehicle-to-grid option has not been explicitly considered. Given the significant on-board battery capacity installed in the fleet of several 100 million vehicles, these batteries could potentially displace a significant proportion of the stationary storage fleet, provided the right incentives and cost developments.

Sixthly, storage will find its role, but costs need to continue to drop. Learning and experience curves need to keep pace with the necessary deployment of VRE sources. If the expected cost reductions are not achieved in time to scale-up storage it may slow down the energy transition, increase the cost of transition and possibly allow for more variable non-fossil and low carbon generation to play a larger role.

Seventhly, hydro should be used more flexibly. The vast hydropower deployment in China presents a unique opportunity to maintain and develop a sizable flexible and low-cost resource on the generation side. This will provide balance VRE generation. The operational model of hydropower stations in China must change, from a comparatively low value proposition of baseload power, to a nimble marketing position, selling power at the right time into the right markets. This perspective needs to permeate also the way that existing and new hydro stations are connected to the local grids and to the interprovincial and interregional transmission grids.

Eighthly, nuclear power plays a minor role in the scenarios. This is by assumption and scenario design. Nuclear and potentially CCS could provide an alternative to the very wind and solar centric power transition. However, these technologies present challenges in a system with the fluctuating netload. Nuclear power does not contribute to balancing the system. This mainly due to the economics, rather than the technical limitations or constraints imposed in the modelling. Viable coal CCS plants would likely share this characteristic as they are also capital intensive 'baseload'-style generation assets. It should be noted that in the scenario modelling coal and natural gas generation with CCS is an option for the model's capacity expansion however it is not selected. This is a matter of cost assumptions of renewables, fossil-fuels, CCS and CO2.

Ninthly, the way power system operates with large penetration of renewables will be changed. On one hand, local balancing of generation and demand is more important than how it is treated as today. Distributed power sources, e.g., roof-top solar panels are installed behind meters, and power distribution system may experience bi-directional flow of energy, and cascading failure of system may be triggered by distributed power sources. On the other hand, interregional power exchange is essential to allow high penetration of renewables in the system. Transmission lines allow high regional fluctuations of power generation and demand, and serve as flexibility providers that assist system balancing in a larger range of area.

Tenthly, proper implementation of needed policies is key. The inherently positive developments in both scenarios' energy transition relies predominantly on current proven technologies and on the implementation of reforms with respect to power markets, subsidy schemes and carbon pricing. These will encourage stakeholders in the market to act in accordance with the vision of the energy transition. The current policy direction is decided and has been shown to work in international markets. These markets are in the front of the energy transition but also in the state of continuous reform, this shows the need for continued learning. For the power system's transition to develop as smoothly and successfully as in the scenarios, these reforms must be fast-tracked and successfully implemented in China to satisfy China's conditions and challenges in the sector.

11.2 Power generation and capacity evolution

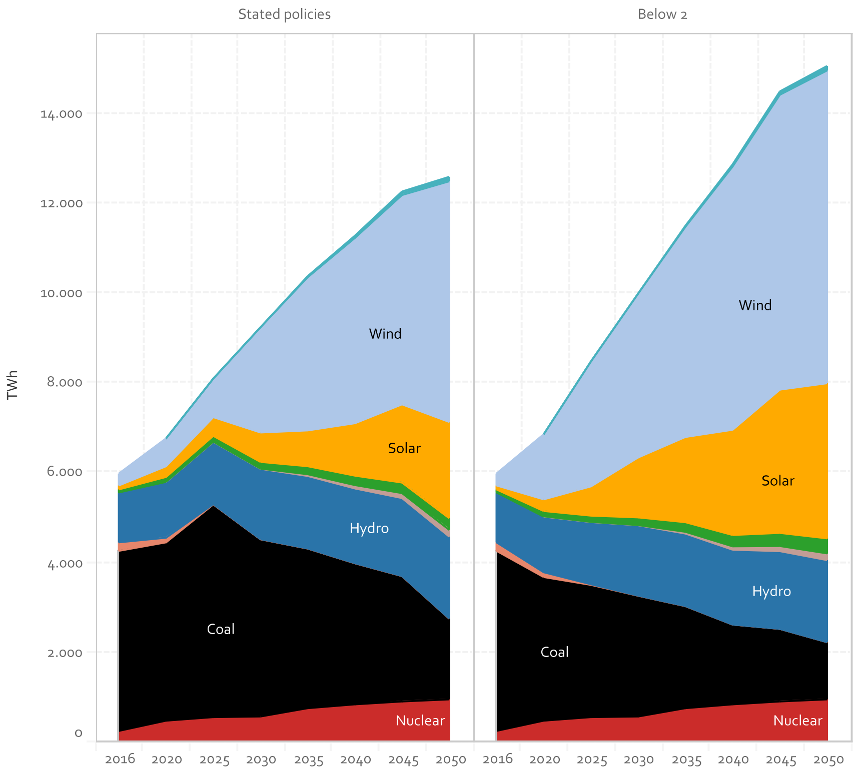
In the power sector, both scenarios describe pathways which significantly transform the power system moving away from the status quo. In the Stated Policies scenario, with the economic development in China and the progress of electrification, power demand is increased by approx. 50% in 2030 and more than 100% in 2050 compared to the level in

2016. The progress of electrification is even more significant in the Below 2 °C scenario, which makes the power demand growth in both mid-term and long-term even higher. The rate of growth in both scenarios start to drop after 2020, and even lower from 2045.

Fossil fired generation peaks in 2025 in the Stated Policies scenario, while pursuing the Below 2 °C scenario forces fossil fired generation to peak before 2020. Nuclear power takes on an expanding role in both scenarios. In both scenarios increased renewable energy penetration is the main development, however, in the Below 2 °C scenario renewable energy quickly becomes the backbone of the power system. Wind power develops into the largest share of power generation in both scenarios. In the Below 2 °C scenario, solar power generation accounts for the second largest.

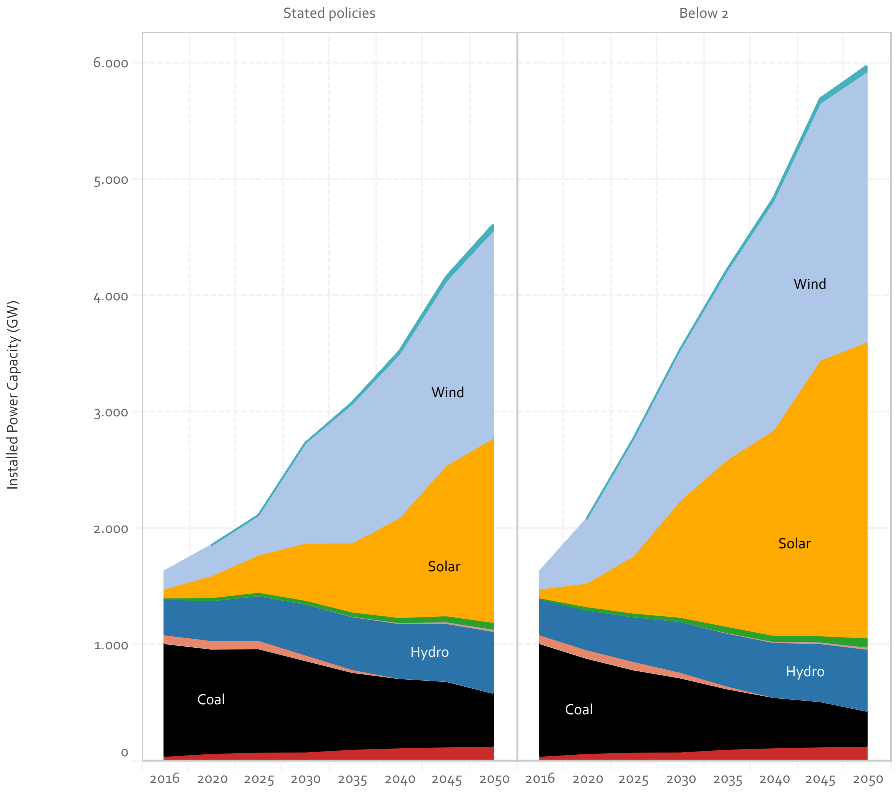
Nuclear power also increases and accounts for the same generation in absolute terms in both scenarios, as the capacity development is identical according to the scenario assumptions, and the variable operating costs are low, once the nuclear power stations are built. Since all nuclear plants are sited in coastal provinces, they are able to run with a capacity factor above 85% in both scenarios. Hydropower also follows the same path of capacity development by assumption. As the power system and market is developed with increased flexibility relative to the current setup, hydro curtailment does not occur in the future. Therefore, the hydro generation also follows the same path in the two scenarios in absolute terms. Since the power demand is higher in the Below 2 °C scenario, the proportional contribution from hydropower and nuclear power is less in the Below 2 °C scenario.

Figure 11-1 Power generation (TWh) from 2016 to 2050 in the two scenarios.



	Stated policies					Below 2				
	2016	2020	2030	2040	2050	2016	2020	2030	2040	2050
Grand Total	5.942	6.723	9.199	11.237	12.548	5.942	6.818	9.950	12.824	15.015
Ocean		0	1	50	100		0	1	50	100
Wind	265	619	2.344	4.123	5.358	265	1.451	3.650	5.857	6.963
Solar	89	237	653	1.169	2.141	89	259	1.334	2.341	3.453
Bio	67	106	149	208	261	67	118	171	252	335
Geothermal		4	4	76	148		4	4	76	149
Hydro	1.108	1.241	1.566	1.664	1.825	1.108	1.241	1.566	1.664	1.825
Natural gas	189	106	3	2	2	189	105	2	0	0
Oil	1					1				
Coal	4.009	3.967	3.946	3.141	1.799	4.009	3.196	2.688	1.779	1.274
Nuclear	213	442	534	803	915	213	442	534	803	915

Figure 11-2 Installed power generation capacity (GW) from 2016 to 2050 in the two scenarios.



	Stated policies					Below 2				
	2016	2020	2030	2040	2050	2016	2020	2030	2040	2050
Grand Total	1.619	1.925	2.826	3.565	4.651	1.619	2.215	3.695	4.841	5.967
Ocean		0	1	25	50		0	1	25	50
Wind	149	259	858	1.403	1.782	149	549	1.292	1.966	2.320
Solar	77	188	490	856	1.580	77	200	1.000	1.760	2.539
Bio	12	26	33	43	57	12	29	35	52	78
Geothermal		1	1	10	20		1	1	10	20
Hydro	305	341	435	469	529	305	341	435	469	529
Natural gas	70	72	51	12	34	70	70	47	1	1
Oil	4	4	3	2	2	4	4	3	2	2
Coal	967	977	886	639	476	967	964	811	450	307
Nuclear	34	58	70	105	120	34	58	70	105	120

The difference between the two scenarios is more profound from the perspective of the development of the generation capacity mix. The development of solar and wind installed capacity dominates the picture. The total installed capacity of power plants in China is expected to increase significantly in both scenarios. The installed capacity in the Stated Policies scenario will reach 2826 GW in 2030 and 4651 GW in 2050 respectively, while it in the Below 2 °C scenario will reach 3695 GW and 5967 GW in 2050 respectively. It is driven by the increase power demand. Additionally, in relation to the generation mix, this is due to the relatively lower number of full load operating hours of wind and especially solar vis-à-vis conventional generators.

In both scenarios, the installed capacity of coal power plants has been decreasing since 2016. This trend in the Below 2 °C scenario is more significant than in the Stated Policies scenario due to a stricter CO2 Budget and a higher RE penetration. The trends of natural gas and nuclear in both scenarios are treated the same. The capacity of natural gas power plants remains the same level until 2025, then start to reduce and fall out of the portfolio in 2040. Due to the maturity of nuclear power technology, the capacity increases gently to 70 GW in 2030 and to 120 GW in 2050 respectively. Oil remains insignificant in the capacity portfolio. Wind and solar will surpass hydro become the first and second largest in the renewable capacity portfolio before 2030, and will surpass coal become the first and second largest ones in the whole capacity portfolio before 2050. The share of renewables is even higher in the Below 2 °C scenario than in the Stated Policies scenario.

In both scenarios, the non-fossil and renewable energy proportion of the power generation therefore increases substantially. The ratios increase from an initial level of 26% RE and 29% non-fossil in 2016, to 78% and 86% in 2050 in the Stated Policies scenario and 85% and 92% in the Below 2 °C scenario. Coal power as which accounts for retreats from its share in the power generation mix from ~67% in 2016 to only about 14% in the Stated Policies scenario and 8% in the Below 2 °C scenario.

Table 11-1 Share of non-fossil and renewable energy in Chinese power generation in the Stated Policies and Below 2 °C scenarios.

		2016	2020	2030	2040	2050
States Policies	Non-fossil energy	19%	39%	3.57%	72%	86%
	Renewable energy	26%	33%	51%	65%	78%
Below 2 °C	Non-fossil energy	29%	52%	73%	86%	92%
	Renewable energy	26%	45%	68%	80%	85%

Natural gas is for the most part absent from the generation mix, which is a consequence of the modelling assumptions and the projective of the market conditions from the current situation. While there is much discussion about the role that natural gas can play in the future, including as relates to balancing increasing volumes of variable renewable energy, the flexibility offerings from new natural gas installations is not economical on a cost basis, subject to the assumptions. The lower CO2-emissions value is not a cost competitive to the renewable options in the short term, and in the longer-term given the tight carbon constraint applied to the power sector in the Below 2 °C scenario, coal and natural gas plants would need to have carbon capture and storage, if they are to play a larger role in the power generation mix. While this would be possible, and is an option included in the modelling, this is also not economically competitive to other decarbonisation options. Finally, in this outlook, no special considerations have been implemented to push for natural gas power development to play a role in the development of the future generation mix. In reality, cities and provinces affected by air pollution, such as Beijing, are implementing natural gas fired power generation and CHP generation to remove dirty coal.

Given that the Chinese power system has historically been characterised by its coal intensity, and that historically, the main source of renewable energy has been hydropower, especially from large projects like the Three Gorges, both scenarios. As has been previously mentioned, the key challenge for the successful development and transition of the power sector towards a clean and low-carbon system, lies in finding new solutions for establishing and maintaining the supply and demand balance, with reduced reliance inherently dispatchable units. Meanwhile, in the transitional period, it is imperative to extract as much value of the flexibility that legacy assets have, since the long-term flexibility, according to the present scenarios must be provided increasingly through grid assets, the demand side and finally storage. The development of these aspects of the power system in the scenarios are covered in the following sections.

Regional generation mix

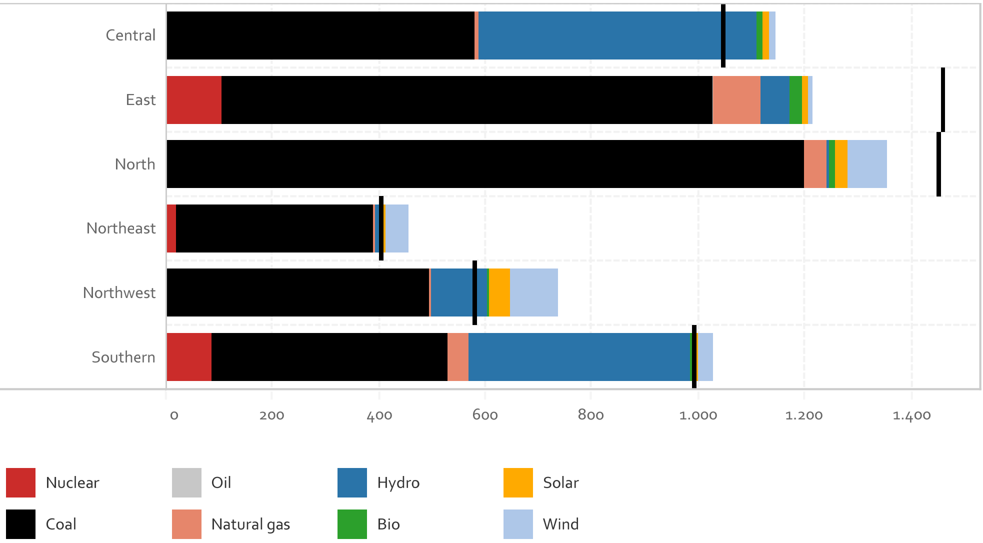
Following figures show how power generation by type as well as also power consumption (black bars) evolve in different regions. The regions are illustrated in the map in Figure 7-1. East China and North China are where power consumption is concentrated in medium term. The proportion of power consumption in Central China keeps increasing and becomes the largest in 2050. Northwest of China will also gain more proportion along these years. This is due to active policy supports on promoting industrial development and upgrading under these regions as well as heavier electrification during the transformation of outdated energy usage patterns, which will be further specified in the next subsection.

In both scenarios and in all terms, Central China and East China import power from outside. North, Northeast and Northwest China are the three regions always export power, due to their rich energy resources, especially renewable energy resources. Southern China can almost obtain the balance of power generation and consumption in short-term and medium-term in the Stated Policies scenario. Due to the reduction of fossil fuel and electrification, Southern China has more wind production in the Below 2 °C scenario in 2020 and 2030 and thus exports power to other regions. With the development of offshore wind and ocean energy, more power can be obtained in Southern China in 2050.

In the figures, black lines show the annual power consumption in different regions. Bars in different colours indicate power generation of different kinds of resources. From the perspective of power source, coal shares very little generation in Southern and Central China in 2050. The share of coal decreases significantly in all regions, especially in the

Below 2 °C scenario. Power production of wind and solar grow more significantly in where is loaded in short term, and the growth moves to where wind and solar resource is rich in longer terms. As nuclear power generation is not easily adjusted, it is quite stable along the years and across scenarios. Hydro has a very big share in Central and Southern China, but its proportion drops as wind power production surpass it and becomes the most significant kind in the whole system.

Figure 11-3 Power generation and consumption by regional grid in 2016 (TWh)*

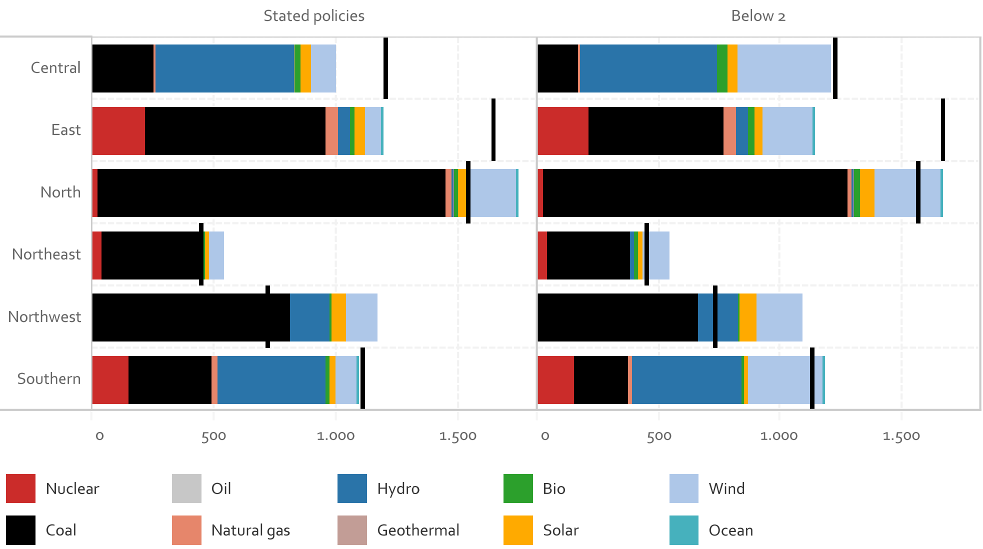


** Generation is a modelling result may differ from generation statistics.*

Short-term 2020

Coal power generation still dominates in the whole structure in both scenarios. In the Below 2 °C scenario, as CO2 target tightens the share of fossil fuel generation, the share of coal generation in this is a bit less than in the Stated Policies scenario, and wind is the major source that substitute its share, especially in Central China, East China, and Southern China where is densely populated. As Central China and Southern China provides a large amount of wind generation in the Below 2 °C, the power is mostly balanced within the region. Thus, the ratio between overall power exchange among regions and total power generation is less than in the Stated Policies scenario.

Figure 11-4 Power generation and consumption by regional grid in 2020 (TWh) *

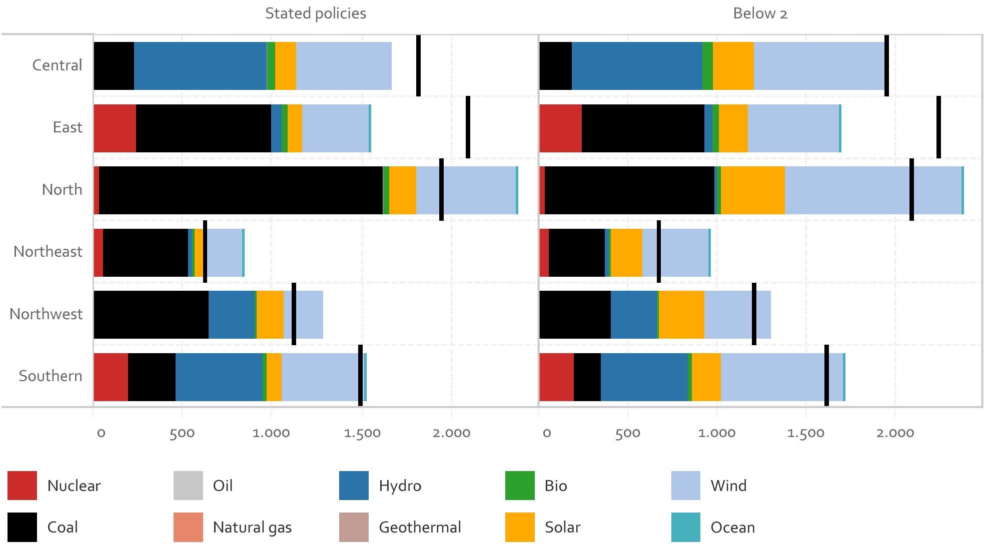


** Note that the axis scale is adjusted from the previous figure due to the growth in overall generation.*

Medium-term 2030

Compared to 2020, the proportion of coal power production is significantly reduced, especially in the Below 2 °C scenario in North China. The share of coal production in north China is reduced to less than 50% from more than 75% in 2020 in the Below 2 °C scenario. Wind becomes the largest power provider in the structure in the Below 2 °C scenario. Solar production also contributes a lot. As the CO2 target is most critical in 2030 than other periods, the difference between two scenarios is most obvious. Renewable energy already becomes the major source in the power sector in 2030 the Below 2 °C scenario. The increase of wind and solar start to shift from Central, East and Southern China to North China where both power demand is high and renewable energy resource is rather rich.

Figure 11-5 Power generation and consumption by regional grid in 2030 (TWh)*

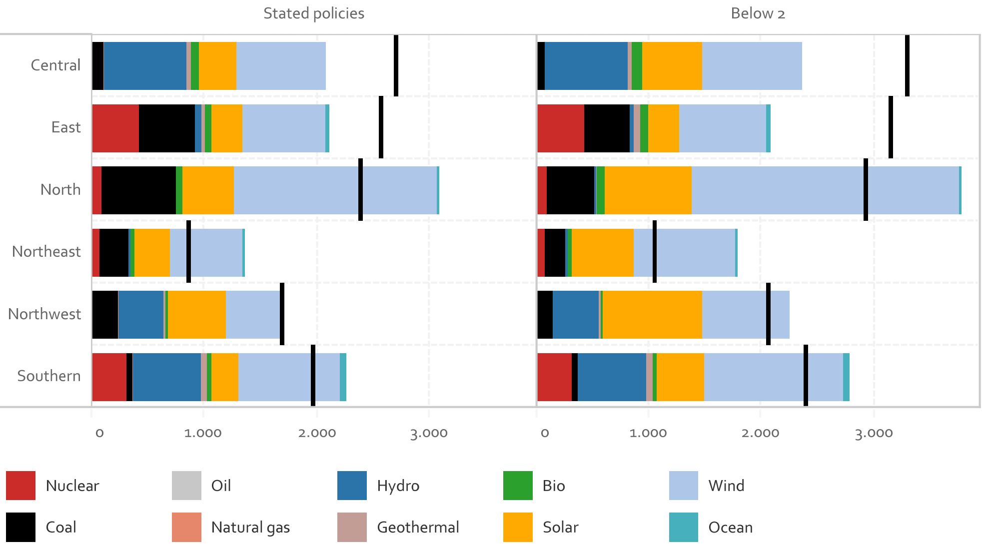


** Note that the axis scale is adjusted from the previous figure due to the growth in overall generation.*

Long-term 2050

Power demand in 2050 has increased significantly since 2030. More renewables produce power to catch up with the demand growth. In Northeast and Northwest China, where large scale renewable projects can be deployed, wind and solar production increases, benefited from local demand growth due to electrification and industrialization, and also from more integrated power system and flexible power market. Renewable is the major source in the whole structure in the Stated Policies scenario.

Figure 11-6 Power generation and consumption by regional grid in 2050 (TWh)*



** Note that the axis scale is adjusted from the previous figure due to the growth in overall generation.*

11.3 Demand development

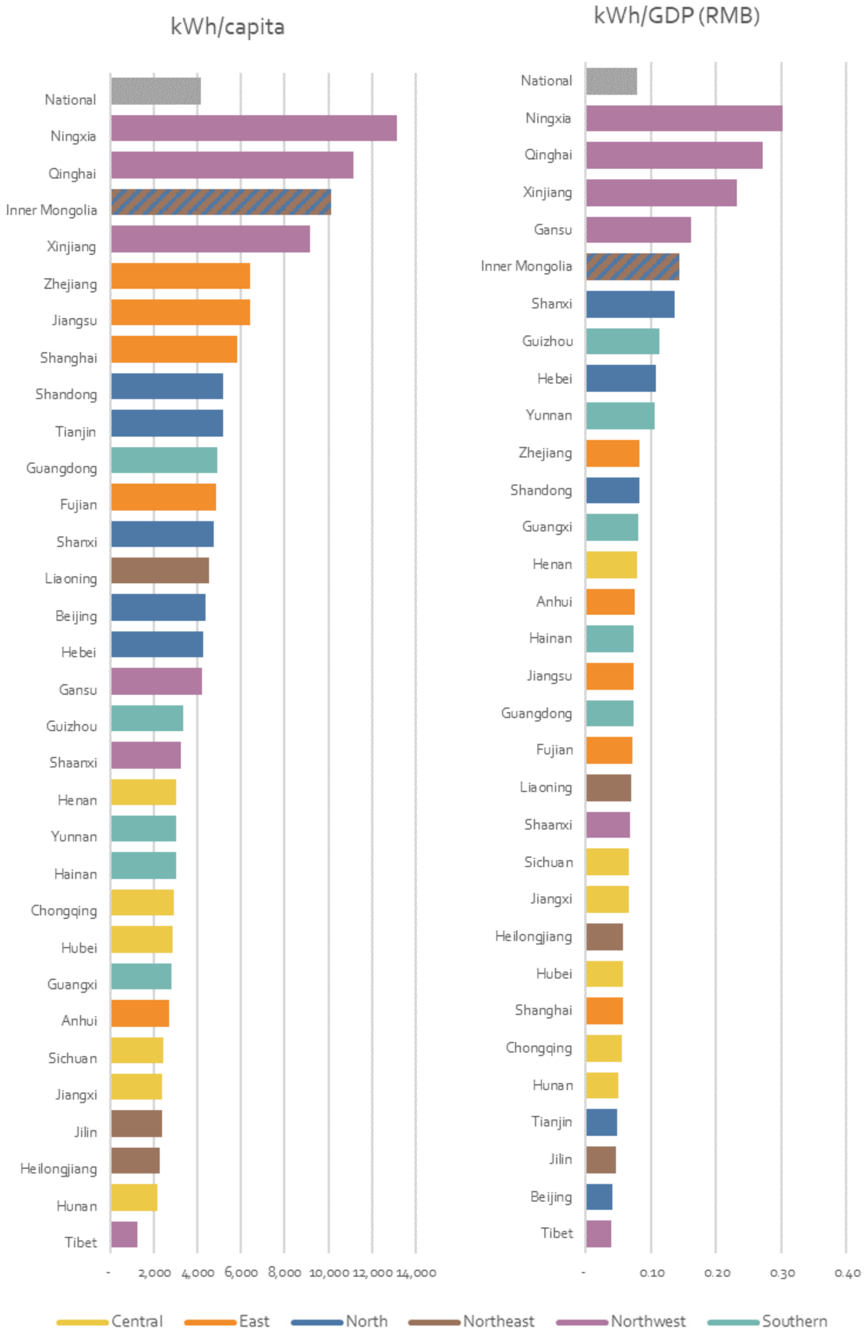
In the two scenarios, the gross power consumption increases from 5900 TWh in 2016 to 12000 TWh in 2050 in the Stated Policies scenario and 14700 TWh in 2050 in the Below 2 °C scenario. The difference arises from increased emphasis on electrification in the Below 2 °C scenario. The electricity consumption in 2020 is 6600 TWh and 6700 TWh in the Stated Policies scenario and the Below 2 °C scenario. This is slightly under the estimation used in the 13th FYP of between 6800-7200 TWh. The 2030 electricity demand is 9000 and 9700 TWh respectively in the two scenarios, which is slightly lower than the range 9100-9800 TWh offered in the 2016 CREO report but essentially in the same ballpark. These figures, however, do not include the additional power consumption for losses in storages and for power to heating, which are calculated endogenously as part of the electricity and district heating supply.

Regional load development

In absolute terms China's electricity consumption is concentrated in the most developed areas of coastal China, as well as the more populous provinces such as Henan. Based on the strategy of strengthening economic development in the Western regions away from the costs, the geographical distribution of demand is not expected to be maintained in perpetuity.

Electricity consumption in the different provinces of China has very diverse characteristics. The level of affluence and population density of course play a major part, but as the industrial sector is the biggest power consuming sector, the industrial structure and the location especially of energy intensive industries should not be overlooked. Figure 11-7 shows the diversity between the provinces in terms of power consumption per capita and per unit of GDP. The sparsely populated North-Western provinces, such as Qinghai, Ningxia and Xinjiang top both lists together with Inner Mongolia. The Eastern provinces are high on both lists with both significant energy intensive industries along the coast, and an affluent population. The same goes for several of the Northern provinces. The central and North-Eastern provinces mostly populate the lower end of the list. The Southern provinces are on the lower end of per capita consumption but generally above the median in terms of electricity intensity. Beijing is in the middle in terms kWh/capita but low with respect to electricity intensity, which is evidence of a more service oriented and economy with high value functions. Tibet is at the bottom end of both lists, and combined with its sparse population and comparatively low GDP, it's also at the bottom in terms of electricity consumption in absolute terms.

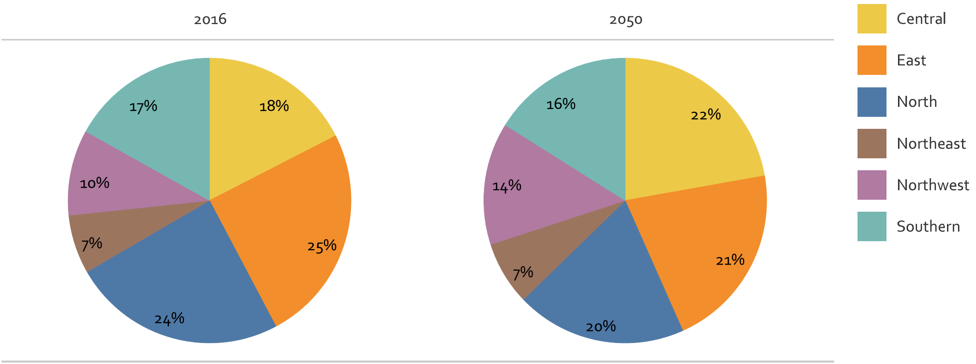
Figure 11-7 2015 electricity consumption per capita (l) and electricity consumption per GDP (r) Source: Calculations based on National Bureau of Statistics



In Figure 11-8 the distribution of electricity demand on the mayor grid regions is shown for 2016 as well as for the two scenarios in 2050. The share occupied today by the well-developed East, North, and South regions is expected to decline, while the share of power consumption in the North-East North-West and Central regions are expected to increase.

While the electricity consumption increases more in the Below 2 °C scenario than in the Stated Policies scenario, the development of the distribution in the two scenarios is the same, resulting from a series of symmetric underlying assumptions on the growth rates in each province.

Figure 11-8 Annual load distribution by grid regions in 2016 and 2050 in the two scenarios*

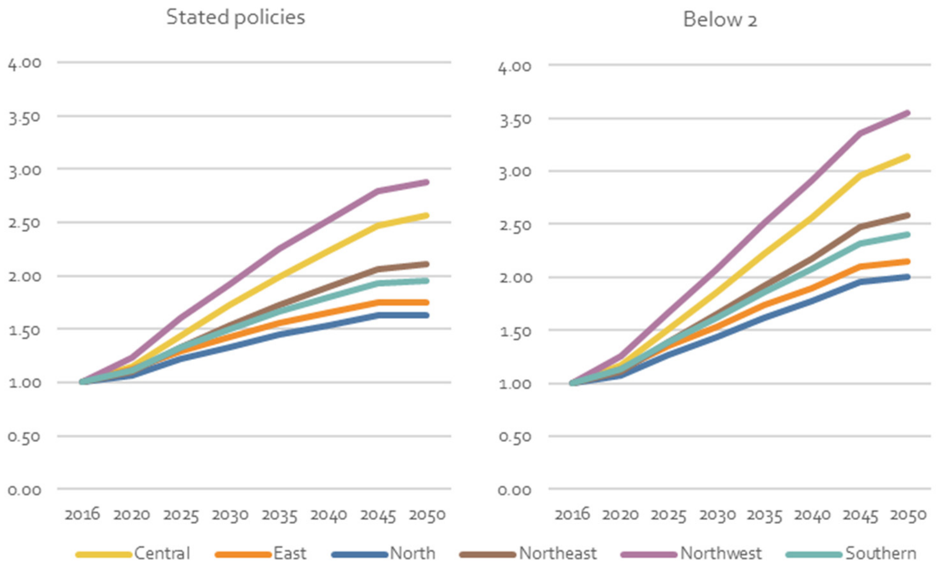


** 2016 regional distribution is based on the China Electricity Council (CEC) preliminary statitics for 2016. 2050 numbers based on CNREC internal projection of the future distribution of consumption.*

The share of demand in Central and North-West grid regions are assumed to grow the most each increasing 4%-points until 2050. The North and East grid regions will decline the most with 4%-points each. Southern grids share power consumption is decreased by 1 %-point by 2050, while the Northeast grid region remains at a stable 7% of the national consumption.

The relative relocation of future electricity consumption naturally has significant impact when it comes to the siting of new generation and the need for new transmission systems. Growing more load in the West, for instance, ceteris paribus reduces the need for transmission investments for West-East transfer, with significant influence on the results in this outlook.

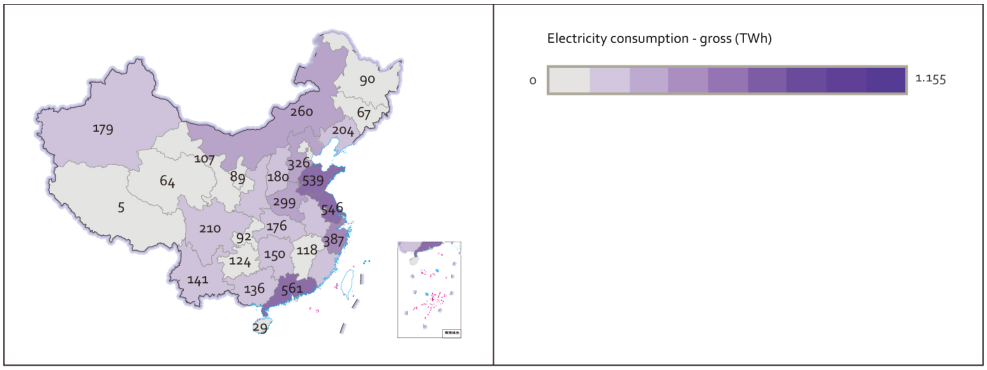
Figure 11-9 Indexed growth of electricity consumption by major grid regions*



** The national development based on the demand analysis in Chapter 10. Regional differences arise from the internal CNREC projection as illustrated* on *Figure .*

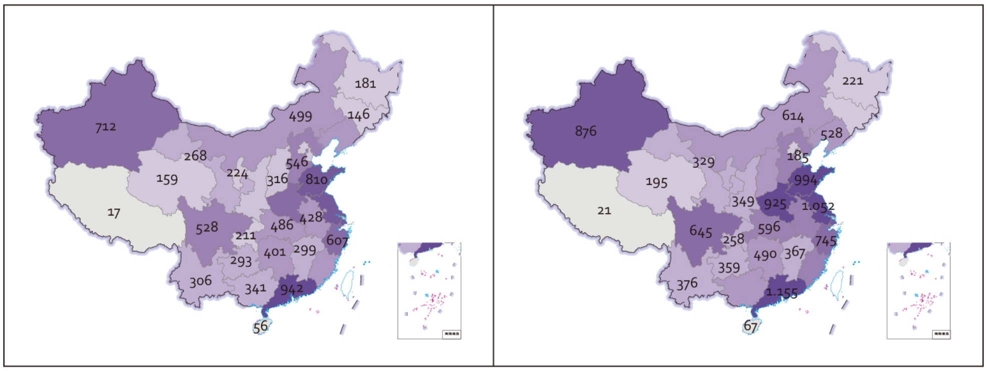
Figure 11-9 shows development of power consumption in the two scenarios by grid region indexed to power consumption in the grid region in 2016. Power consumption in the North-west grid region increase by a factor of 2.9 and 3.5 in the state policies scenario and the Below 2 °C scenario respectively. The Central grid increases by 2.5 and 3.2 respectively. The North-East grid increases by a factor of 2.1 and 2.6 respectively, which is about national average increase in the two scenarios. Southern grid demand increases by 2.0 and 2.4 respectively in the two scenarios, while load in the East China grid increases by a factor of 1.7 and 2.2 respectively. Finally, the North China power grid load increases by a factor of 1.6 and 2.0 in the stated policies and the Below 2 °C scenarios respectively.

Figure 11-10 Electricity demand annually by province in 2016 and 2050 in the two scenarios (TWh).



Stated policies

Below 2



In Figure 11-10 the electricity consumption assumptions are mapped by provincial power systems, showing the distribution of base year, 2016, power consumption and the final year's power consumption in 2050.

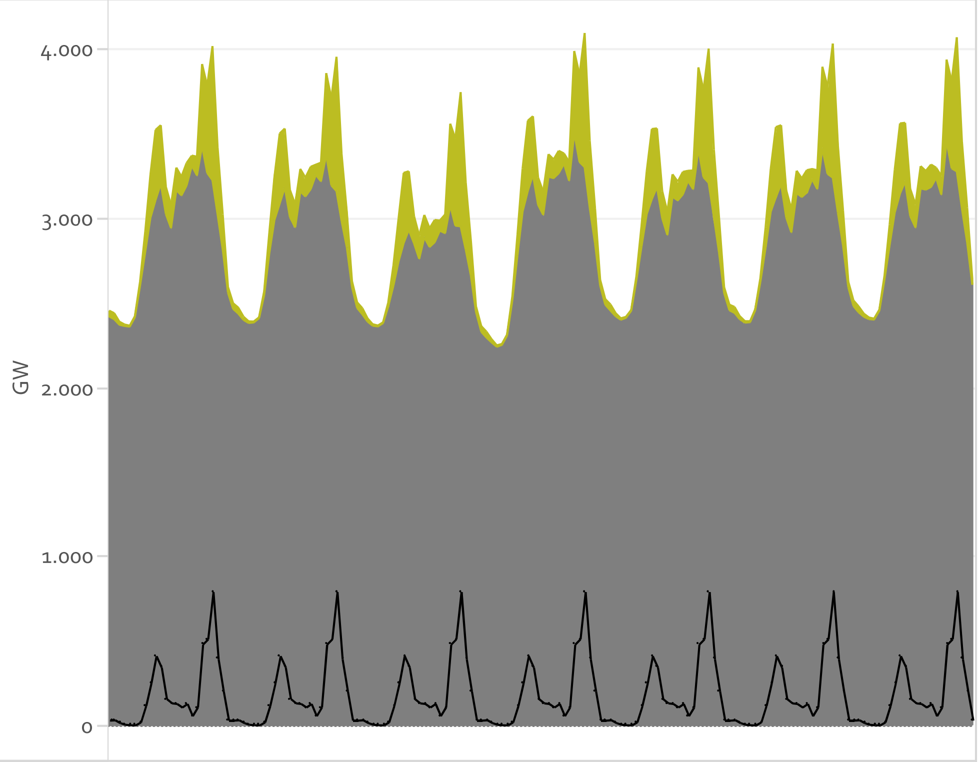
Load shape evolution

An all-important piece of data input to producing reliable power sector scenarios is the shape of the power consumption. To verify the derived power systems ability to balance itself, it is best practice to use a fine-grained time resolution for the dispatch simulations done to hourly, or even sub hourly level. In China, this data is unfortunately difficult to come by and as such, this study relies on a combination of real and synthesised representative data, which are adjusted according to key rations provided in the statistics of the China Electricity Council. Hence the modelling is carried out with reasonably representative time series for power demand at provincial level (except for Inner Mongolia which has separate profiles for East and West) for the starting point.

Unfortunately, historical data is also of limited value for creating representative scenarios for the future power consumption, especially with the backdrop of an economic transition from and energy intensive economy and further the energy transition, where EV's and other forms of electric mobility play an increasing role.

The evolution of the load shape applied in this study focuses narrowly on the impact of EV penetration. This focus stems from the electrification emphasis in the demand side modelling, where electric mobility is a key component. Moreover, the opportunities from smart charging electric vehicles plays a key role in the power sector modelling. Thus, provincial load shapes are a function of the estimated historic load shapes plus the weighted addition of the assumed load shape from EV charging (non-smart).

Figure 11-11 Illustration of the exogenous hourly load shape assuming non-smart EV loading (top area and line) and other load in 2050 of the Below 2 °C scenario.



Demand response

Demand response (DR) involves an end-user's ability to reduce/increase their electric load in response to price signals or other incentives and regulations. DR as a flexibility option requires both physical flexibility from responsive loads, and the appropriate institutional structures to incentivise the desired response. These frameworks are assumed to be developed as part of the power market reform process, and the available response capacity is as shown in Table 11-2.

The development of the demand response potential in the Below 2 °C scenario is based on an extrapolation of the conclusions of the Environmental Change Institute's (ECI) study on demand response market potential in Shanghai. This study finds that the participation rate of direct load control for residential in 2030 will range from 5% to 20%, while for the small commercial and industrial sectors, the figure ranges from 1% to 10%. The participation rate of curtailable programs that are assumed to only be introduced in commercial and industrial sectors range from 2% to 30%.

Given the significant role of air conditioning in the overall electricity use in Shanghai, DR participation in Shanghai could be higher than in other regions. Therefore, a low scenario participation rate (5%) for the residential sector for the national level study. For commercial and industrial sectors, the medium participation rates in Shanghai are applied.

The response rate observed for industrial customers was 80-90% for a requested load reduction of 10%, and the response rate declines considerably (to 30%), in conjunction with higher levels of requested load reduction (up to 50%).

Demand response from the residential sector is assumed to constitute peak shaving, where the electricity demand reduced is not moved to the off-peak period. However, for commercial and industrial sectors, it is assumed that the demand response leads to load shifting, as the overall outputs/services remain the same if the production profile is modified.

Table 11-2 Available demand response capacity (MW)

		2016	2020	2025	2030	2035	2040	2045	2050
States Policies	Peak shaving	142	787	1.876	3.197	4.177	5.173	6.322	7.168
	Load shifting	475	2.374	4.747	7.121	8.308	9.494	10.681	11.868
	Total	**617**	**3.161**	**6.623**	**10.318**	**12.485**	**14.667**	**17.003**	**19.036**
Below 2 °C	Peak shaving	142	801	1.976	3.504	4.777	6.367	8.351	9.890
	Load shifting	475	2.374	4.747	7.121	8.308	9.494	10.681	11.868
	Total	**617**	**3.175**	**6.723**	**10.625**	**13.085**	**15.861**	**19.032**	**21.758**

The total capacity for load shifting is 2.3 GW in 2020, 7.1GW in 2030 and 11.8 GW in 2050 in both scenarios. This capacity is distributed according to the distribution of industrial load, and as such is predominantly located in the industry-intensive provinces in China. The potential residential demand reduction is 787 MW in 2020, 3.2 GW in 2030 and 7.2 GW in 2050. Due to higher electrification, the response potential is slightly higher in the Below 2 °C scenario with 801 MW in 2020, 3.5 GW in 2030 and 9.9 GW in 2050. Geographically this load is distributed by the load peak without considering EV charging load.

Electric vehicles and smart charging

Since 2015 China has been the largest EV market in world with annual sales over 500,000 EVs in 2016. The national target is to exceed 5 million EVs by 2020. The passenger vehicle projection, presented in the energy demand outlook, shows that by 2030 there are 100 million EVs and by 2050 400 million EVs (stock). Based on projection of the increasing sales of EVs and the turnover in vehicle stock it is estimated that the on-board capacity of EVs' charging capacity is 50 GW 2020 in the Stated Policies scenario and 70 GW in the Below 2 °C scenario. Of these only a negligible amount is assumed to be smart charged in 2020, but by 2030 50% of these vehicles will be smart charged and by 2040 and beyond all passenger EV's will be smart charged. The on-board vehicle storage charging capacity is 150 GW in 2030 in the Stated Policies scenario and 800 GW in the Below 2 °C scenario. In 2050 this is 400 GW and 3200 GW respectively for the two scenarios.

The availability of the smart-charge load reduction is primarily limited by the loading pattern than would otherwise be followed, as show in Figure 11-11. The maximum load adjustment from reduced charging of EVs is Table 11-3, which is at the time of peak charging of non-smart EVs. This is based on the default (non-smart) charging profile.

Table 11-3 Maximum available load reduction (GW) from EVs

	2020	2025	2030	2035	2040	2045	2050
States policies	-	6	21	50	97	132	168
Below 2 °C	-	14	61	156	356	513	622

Particularly in the Below 2 °C scenario, the potential to use EV smart charging as demand response is significant. Obviously, this provides a larger and important piece of flexibility. The value of the EV with smart charging package, is an additional load which can be timed to when it is valuable to have increased consumption.

11.4 Grid development

In two scenarios, existing interprovincial transmission lines, ultra-high voltage AC and DC lines were mapped in the model with their capacity and regular operating characteristics. In addition, interprovincial and interregional transmission lines planed in 13-FYP are also put into our model for short-term condition. The planning for power transmission expansion after 2020 is not published yet. In order to allow the power transmission among provinces and regions, power transmission expansion is considered in the model to fulfil the need of power exchange, to allow better allocation of resources and to accommodate high penetration of renewables in the system, which can be discovered from the results.

Cost of interprovincial grid expansion

The cost of interprovincial grid expansion is based having two invest in transmission substations in the source and destination ends, as well as a cost per kilometre per MW of capacity.

The key assumptions going into this are the distance between provincial grids as well as:

- The cost per substation of 700,000 RMB/MW

- The cost of transmission lines of 2500 RMB/MW/km

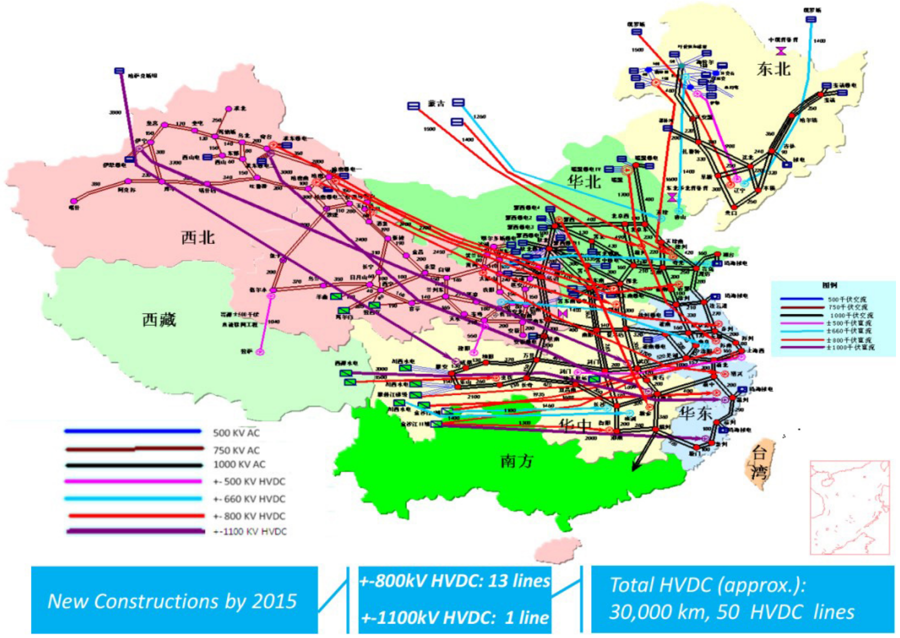
These costs are estimated by CNREC based on consultation with experts. The implication of these costs is that a system benefit of expanding the transmission capacity between two regions, must be high enough to cover the annualised investment in new transmission, for the simulated capacity expansion to occur.

Power transmission

Short-term 2020

By 2015, total 50 HVDC lines are constructed in China, which transmit power over 30,000 km. These HVDC links are mainly used for long distance transmission and asynchronous systems connections. New UHVDC projects are undertaken, including thirteen +/-800 kV and one +/- 1100 kV HVDC links, as shown in Figure 11-12.The mixed UHVDC, HVDC and HVAC will compose the Chinese backbone transmission system.

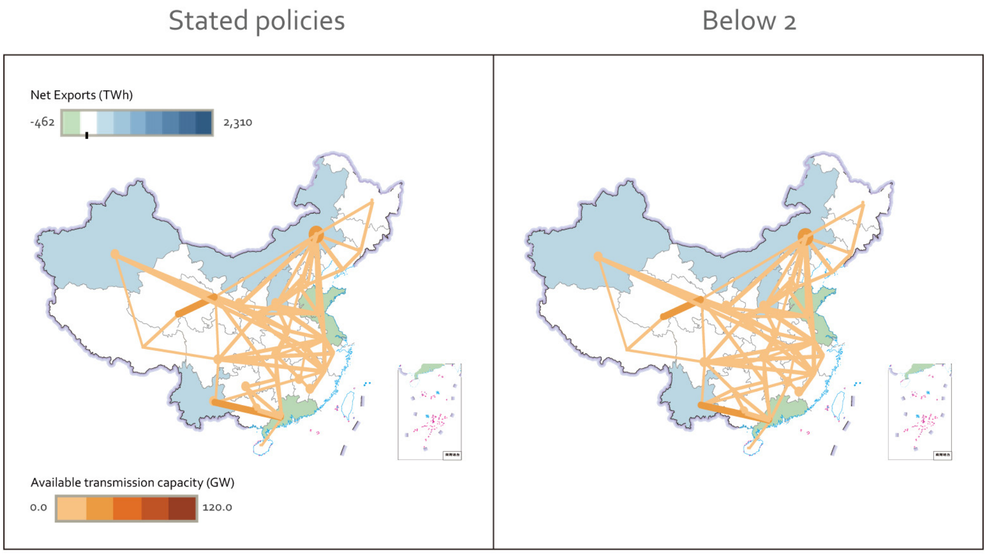
Figure 11-12 Illustration of the current and planned expansion for UHV projects in China.



In both scenarios by 2020 the overall transmission situation is to a large extent and extension of the current situation, however we do see a growth in imbalances between importing and exporting provinces, as new generation development is unevenly distributed and long-distance transmission lines which are already planned or under construction are finalised. It is anticipated that the capacity of interprovincial and interregional power exchange will be expanded. The key exporting provinces are Inner Mongolia, Xinjiang, Shanxi, Yunnan, Sichuan, while Beijing, Shandong, Henan, Jiangsu, Zhejiang, Shanghai and Guangdong are mayor importers in both scenarios. In the Below

2 °C scenario imports decline for several of the importing provinces as a significant proportion of additional RE is sited near these load centres.

Figure 11-13 Interprovincial transmission capacity and annual net-exports by province in 2020.



Electricity transmission grid expansions between regional grids until 2020 are presented in Table 11-5. This accounts only for the interprovincial capacity which crosses the regional grid boundaries. The red highlights indicate where transmission capacity expansion occurs between 2016 and 2020.

Between 2016 and 2020 most of the transmission capacity expansion is project which are already decided and/or under construction. All the UHVAC and UHVDC projects constructed and planned until 2020 are listed as follows.

Between North-West and Central China:

Jiuquan - Hunan	±800 kV DC
North Shaanxi-Changsha	1000 kV AC
North Shaanxi—Wuhan	±800 kV DC
East Junggar-Sichuan	±1100 kV DC

Between North and East China

North Shanxi-Jiangsu	±800 kV DC
Xilingol-Jiangsu	±800 kV DC

Between North-East and North China	
Jarud -Shandong	±800 kV DC
Between North-West and East	
East Ningxia - Zhejiang	±800 kV DC
East Junggar-Anhui South	±1100 kV DC
Jingbian-Lianyun'gang	1000 kV AC
Longdong-Jiangsu	±800 kV DC
Between North-West and North	
Shanghaimiao-Shandong	±800 kV DC
Yuheng-Weifang	1000 kV AC
Between Central and East	
Ya'an-Shanghai	1000 kV AC
Between North-East and Central	
Jarud -He'nan	±800 kV DC
Between North and Central	
Zhangbei-Nanchang	1000 kV AC

In addition to the above listed transmission projects, a number of ultra-high voltage transmission lines are also being deployed within the regional grids.

Table 11-4 Ultra-high voltage projects within regional grids

West Inner Mongolia -Tianjin South	1000 kV AC	North
Weifang-Shijiazhuang	1000 kV AC	North
Xilingol -Shandong	1000 kV AC	North
Huainan-Najing-Shanghai	1000 kV AC	East
Yazhong - Jiangxi	±800 kV DC	Centre
Northwest Yunnan -Guangdong	±800 kV DC	South

The Below 2 °C scenario spurs some additional transmission expansions between the Central and North-West regions as well as between Central and South. Naturally, this additional capacity development, would have to be identified and planned very quickly in response to a strengthening of targets for RE and CO_2-mitigation as assumed in the Below 2 °C scenario, in order to be realised in time.

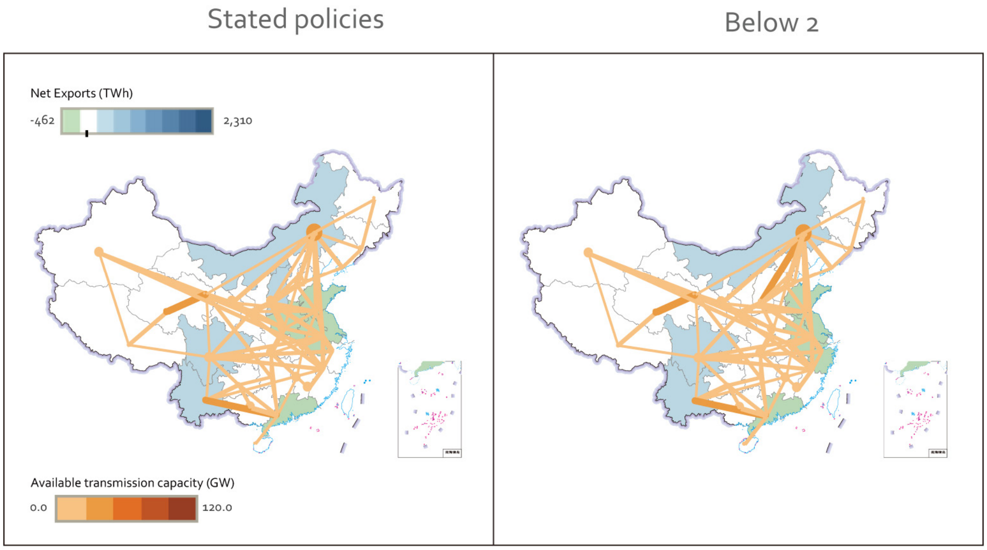
Table 11-5 Transmission capacity (GW) between regional grids in 2020.

		East	North	Northeast	Northwest	Southern
Stated policies	Central	34,2	8,5		30,1	12,5
	East		16,9	9,8	17,0	1,2
	North			44,2	35,2	
Below 2	Central	34,2	8,5		24,4	20,4
	East		16,9	9,8	17,0	1,2
	North			44,2	35,2	

Medium-term 2030

The import export situation shifts considerably towards 2030. Here the main exporting regions become more concentrated, with Inner Mongolia, Sichuan, Yunnan and Shanxi growing their exports.

Figure 11-15 Interprovincial transmission capacity and annual net-exports by province in 2030.



The grid development from 2020-2030 is endogenously determined by the scenario modelling, and here the two scenarios follow two distinctly different pathways.

In the Stated Policies scenario, several transmission capacity expansions involve strengthening the grid to the Central region, including from the North and North-West regions. These capacity expansions are to a certain extend spurred by a concentration of the coal generation to areas with lower coal power generation costs. For instance, the Stated Policies scenario features a larger export from Xinjiang province towards North China which has a higher share of coal power, than the lower exports in the Below 2 °C scenario. The coal base in Shanxi province is also a significantly bigger exporter in the Stated Policies scenario than the Below 2 °C scenario.

Transmission capacity is expanded between the North and East grid regions in both scenarios, however, with greater capacity in the Stated Policies scenario. Furthermore, some of the additional capacity, installed in the Below 2 °C scenario by 2020, is developed in the Stated Policies scenario by 2030, between the Central and Southern grid regions.

In the Below 2 °C scenario, capacity is expanded between the North-East and North, allowing for increased RE power to be sent especially from East-Inner Mongolia to serve load in North China.

The grid expansion allows the utilization of renewable energy from the distance, such as hydro from South-West and Tibet is delivered through the transmission lines. In the meanwhile, distributed renewables have larger share in the new installed capacities which becomes an important complement. In both scenarios, transmission lines form North-West to coastal provinces in long distance and of high capacity are not preferable due to optimal mapping of RE development and high cost of construction of these lines. Instead, a meshed network is built in North-West and between North-West and neighbour provinces to deliver the power and to strengthen the reliability of power grid.

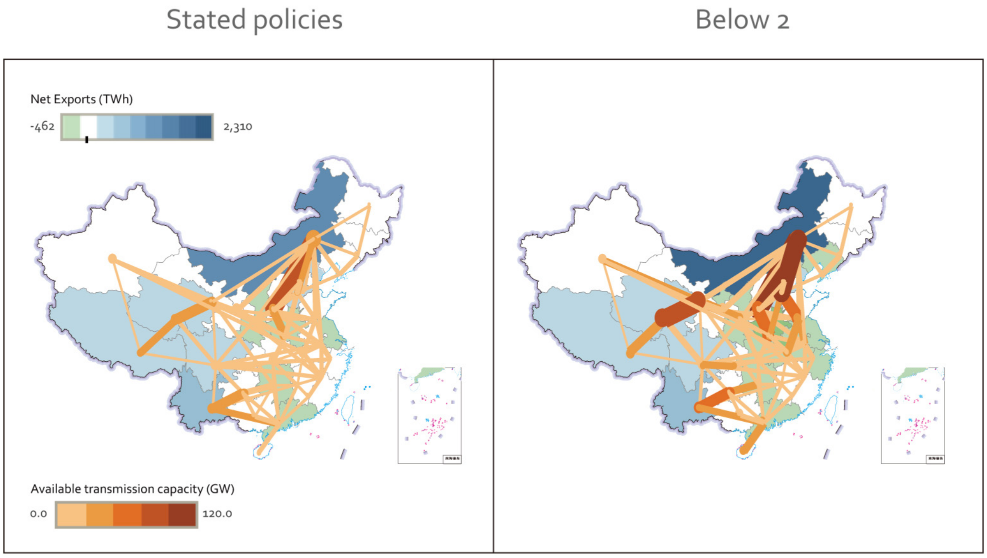
Table 11-6 Interprovincial transmission capacity (GW) in 2030.

		East	North	Northeast	Northwest	Southern
Stated policies	Central	34,2	26,3		30,1	18,3
	East		18,3	9,8	17,0	1,2
	North			44,9	35,2	
Below 2	Central	34,2	8,8		25,3	23,2
	East		18,6	9,8	17,0	1,2
	North			58,7	35,2	

Long-term 2050

By 2050, renewable energy endowed export provinces from Inner Mongolia, Tibet, Qinghai, Yunnan, Sichuan supply a large part of power consumption in the more densely populated Central and Coastal China. Local RE resources close to demand centres are fully exploited, and therefore new generation is again moved to the provinces heavy on resource endowments relative to local demand. Naturally, this must be accompanied by further expansion of the interconnected power grid.

Figure 11-16 Interprovincial transmission capacity and annual net-exports by province in 2050.



In the period from 2030-2050 there is significant transmission capacity expansion between the grid regions. It should be noted, that by assumption this period moves from six distinct regional markets to an integrated national market with coordinated clearing of the supply and demand balance at any given time, as introduced in Section 8.5. Therefore, in this period, the potential benefits of interregional power exchange capacity are enhanced.

The capacity expansion in the Below 2 °C scenario is higher than the Stated Policies scenario along all the interfaces, demonstrating the widely accepted premise that with higher penetration variable renewable energy portfolios the higher the value of transmission capacity and thereby the option to smoothen fluctuations over a larger balancing area. Furthermore, the increasing interconnection capacity, allows a wider scope for connecting variable generation with demand and flexible resources in the broader grid. Finally, in comparison with traditional generation, the resource and demand localisation is less aligned, motivating bulk power transport.

Table 11-7 Interprovincial transmission capacity (GW) in 2050.

		East	North	Northeast	Northwest	Southern
Stated policies	Central	35,7	55,6		40,5	50,7
	East		30,0	9,8	17,0	5,1
	North			89,6	48,4	
Below 2	Central	58,4	89,4		65,9	61,4
	East		83,0	9,8	17,0	11,9
	North			147,1	70,4	

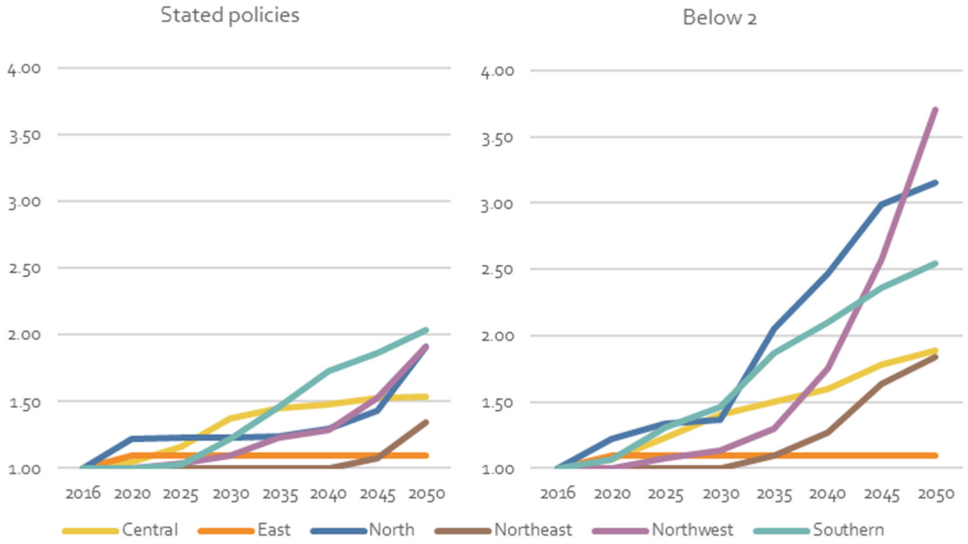
The North-East and North grid regions feature significant increase in interconnection capacity. The key force at play is the very high export of variable renewable energy from Inner Mongolia. Central and North regions are also strongly interconnected, both for balancing and for transport of RE to the Central market load centre. Hydropower in Central and Southern China are also increasingly interconnected both as further generation capacity is developed, but also as balancing and flexibility of the hydro resource receives a premium in the market space. The corridor from Tibet, through Qinghai and Gansu, is significantly stronger in the Below 2 °C scenario, as are the paths from Sichuan and Yunnan to the markets in Central and coastal China.

In both scenarios, by 2050, the transmission system in China has been expanded and further interconnected. It is operated according to market principles connects supply and demand through continuously adjusted pricing mechanisms, which provides higher value to the significant investments in new grid capacity, as is also illustrated later in this outlook.

Intraregional grid expansion

As relates to grid expansion, the previous sections have focused on the interconnection between mayor grid regions, however, there is also significant development of transmission capacity between the provincial grids within each of the regional grids. This includes expansion of capacity for better balancing and trade within the grid region, as well as the capacity which traverses the regional grid, before interconnecting with another mayor grid region.

Figure 11-18 Index for the development of transmission capacity between provincial grids within each mayor grid region.



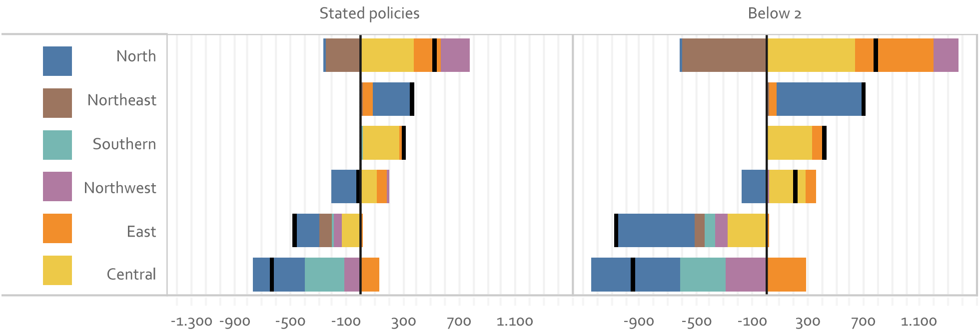
The illustration in Figure 11-18 indicates the scale of the expansion, but should be an index for the development of intraregional grid expansion, based on the sum of intraregional exchange capacities between the provincial grids.

Reinforcements of the Central grid features an increase in interprovincial capacity by 60%-80% with the higher number attributed to the Below 2 °C scenario. The Eastern grid does not expand in either scenarios after 2020, but it should be said that by this time it is already very strongly interconnected. Between 2016 and 2020 there is a 25% increase in the interprovincial transmission capacity in the North China power grid, and while this remains stable until 2040-2045 in the Stated Policies scenario, the capacity expansion from 2030 in the Below 2 °C scenario is significant. The North China interprovincial transmission capacity by 2050 is almost twice the 2016 level in the Stated Policies scenario and over three times the 2016 level in the Below 2 °C scenario. The North-East grid doesn't see allot of internal expansion before 2045 in the Stated Policies scenario and 2035 in the Below 2 °C scenario. The North-West grid internal development is characterised by the development of the Tibet-Qinghai-Gansu pathway towards the markets in the East. This development is considerably more profound in the Below 2 °C scenario. Finally, the Southern grid strengthens the West-East capacity considerably in both scenarios. Finally, Hainan in the South China sea, becomes an offshore wind power export base in the Below 2 °C scenario, where the transmission capacity to Guangdong is developed significantly. Southern grid interprovincial capacity is increased by a factor of 2 in the Stated Policies scenario and 2.5 in the Below 2 °C scenario.

Power exchanges in 2050

Focusing on 2050, this section looks further into comparing the power exchange situation in the two scenarios. As has been mentioned in the previous section, the trade patterns in the Chinese power system evolve over time along two distinct pathways, however, the two scenarios also feature a number of fundamental patterns, which arise in the scenario modelling, on the basis of the common assumptions of technology cost development, demand distribution, resource endowments etc.

Figure 11-19 Net-exports (TWh) from each grid region, to the other grid regions in 2050.*

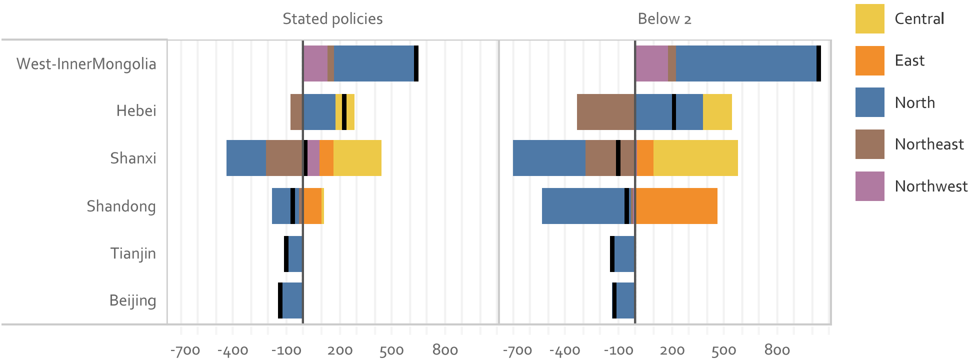


** The black bars indicate the total net export (neg. import) from the grid region indicated on the vertical axis.*

Figure 11-19 shows the net power transmission flows between the mayor grid regions in 2050 by order from main net-exporter to main net-importer. The black bars indicate the net export. The North China grid region is the main exporter to the other grid regions in China in both scenarios, with the main destinations being the central and eastern grids in both scenarios, but especially in the Below 2 °C scenario where the net-exports are largest. To a lesser extent there is also exports to the North-West grid, which is essentially from Inner Mongolia to Ningxia and Shaanxi. As is indicated on the predominant source of North China exports is from the West-Inner Mongolia which is endowed with very large resources, but is relatively sparsely populated and consumption commensurately low. The North-East power grid is also a net-exporter with flows going to or through the North China grid. Additionally, UHVDC connections transmit power directly to Eastern China. China Southern grid predominantly exports to Central China in the Stated polices scenario and additionally exports to eastern China in the Below 2 °C scenario. The North-West power grid in 2050 is at around net zero exports in the Stated Policies scenario, with the aforementioned imports from West-Inner Mongolia, being netted with exports towards mainly Central and to a lesser extent Eastern China. The North-West grid also transmits power towards Northern China, however, these are netted with the imports coming from Inner Mongolia and as such not evident in the charts. In the Below 2 °C scenario, more RE resources are developed in North-West China and the grid region is a net-exporter.

In both scenarios, Central and Eastern China are the recipients of significant net exports. In the Stated Policies scenario the net imports are the highest in Central China, whereas Eastern China receive the most exports in the Below 2 °C scenario. In both scenarios, however, there is a positive net-flow from Eastern to Central China.

Figure 11-20 Net-exports (TWh) in 2050 from North China provinces by destination (neg. origin) grid.



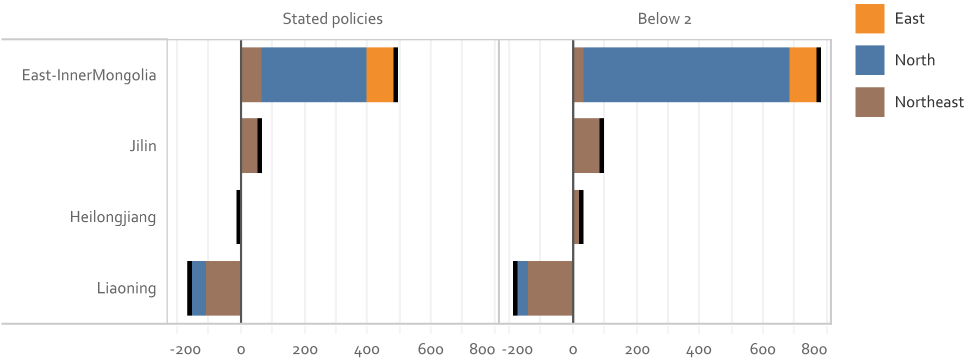
Looking at North China, Figure 11-20 shows by provincial grid, the flows in and out of the province by grid connections. Firstly, the exports from the West-Inner Mongolia grid predominantly flows towards other provinces in the North China area. As previously mentioned power flow also goes towards the North-West power grid, in Ningxia and Shaanxi and finally, for transit through East-Inner Mongolia.

Hebei receives power from the North-East and transits further south North China's other provinces, as well as to Henan in Central China. Shanxi acts as a transit hub for further flows mainly from Inner Mongolia, towards destinations in Central, East and in the Stated Policies scenario also the North-West grid to a lesser degree.

Shandong is in a minor import position in the Stated Policies scenario and more or less in balances in the Below 2 °C scenario, where the total volume of exchange is a lot higher. Shandong receives power through Hebei and other North China provinces, as well as through UHVDC lines from East Inner Mongolia and the Ningxia-Shandong HVDC connection. The destination for Shandon exports are in Eastern China.

Beijing and Tianjin import from North China provinces, especially of course the encircling Hebei province as has been mentioned.

Figure 11-21 Net-exports (TWh) in 2050 from North East provinces by destination (neg. origin) grid.



In the North-East, East Inner Mongolia is the predominant export base, with transmission flows going towards North China and via UHVDC lines to East China, as well as through the three other North-East provinces. The net exports in the Below 2 °C scenario are significantly larger than in the stated policies. Jilin is also a remains a net-exporter, an RE development region. Net-exports in the Below 2 °C scenario are also higher than in the Stated Policies scenario. Heilongjiang is more or less in balance in 2050, with a slight import position in the Stated Policies scenario and a slight export position in the Below 2 °C scenario. Liaoning is a deficit region with imports both from North China and from Jilin and East-Inner Mongolia.

Figure 11-22 Net-exports (TWh) in 2050 from South China provinces by destination (neg. origin) grid.

By 2050, the Southern grid provinces in China retain a relatively more insulated status than the other grid regions. Transmission flows from West to East with Yunnan being the main exporting province and Guangdong the main destination transmission flows. Yunnan, Guizhou and Guangdong also send power on a net basis towards scenario China, although Guizhou on a net-basis is an importer in both scenarios. Guangdong and Yunnan also have a positive net-export position towards East China.

Guangxi has a net-balance transmission position, but is naturally on the corridor for export from Yunnan to Guangdong, which transits both thorough the UHVDC corridors traversing the province as well as through the AC grid. Hainan also develops a strong export position in both scenarios, but with considerably larger volume in the Below 2 °C scenario, where more RE is developed on the Island province.

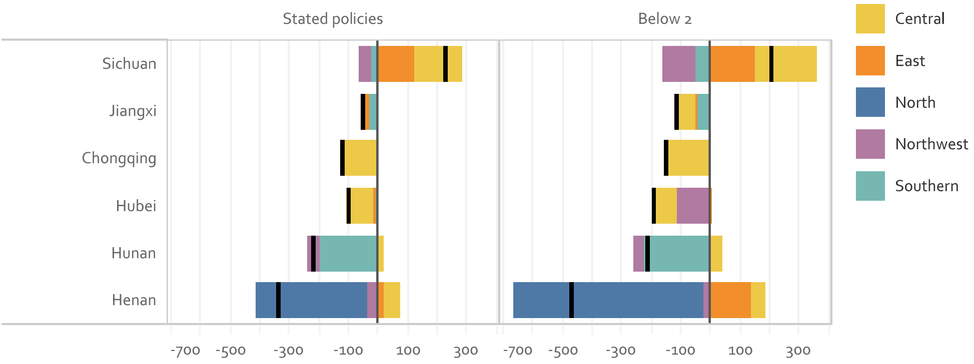
Figure 11-23 Net-exports (TWh) in 2050 from North West provinces by destination (neg. origin) grid.

In North-West China, the mayor export bases by 2050 are Tibet (Xizang) and Qinghai. From Tibet, it is predominantly the significant expansion potential from hydropower, which given the lack of a large local consumption, creates an export imperative through the North-West grid and to a lesser extent through the Sichuan in Central China. While Qinghai also exports to and through Sichuan, Sichuan is itself a large exporter with grid connections to the East. The result is that most of the export flows follow the North-West grid corridors through Gansu, Shaanxi and towards North and Central China. The large volumes of exports coming from Tibet and Qinghai as well as from West-Inner Mongolia, creates congestion towards Central China and North China (less Inner Mongolia), and both Ningxia, Shanxi and Gansu are net importers by 2050 in both scenarios. Xinjiang is in balance by 2050 in the Stated Policies scenario and is actually importing from Tibet and through Gansu commensurate quantities to the exports which flows through its USVDC lines to Henan in Central China and Anhui in Eastern China. In the Below 2 °C scenario, however, Xinjiang is also a net-importer.

Figure 11-24 Net-exports (TWh) in 2050 from East China provinces by destination (neg. origin) grid.

All provinces of Eastern China receive imports of power on a net basis, with the exception of Fujian which is a net exporter in the Stated Policies scenario and a net-importer in the Below 2 °C scenario. Jiangsu is by far the biggest importer in absolute terms, however this stems from the fact that the industrial province is one of the largest in the grid region as well as in China in terms of electricity consumption. Zhejiang is a modest net-importer in the Stated Policies scenario, but the imports are significantly increased in the Below 2 °C scenario. In relative terms, Shanghai is the biggest importer receiving more than half its electricity consumption through imports in both scenarios, mostly through the other Eastern China provinces, but also direct via DC lines from the hydropower bases in Central China. Anhui also has significant imports in both scenarios. Along imports especially from North China, Anhui has a UHVDC connection from Xinjiang. In the Below 2 °C scenario Anhui net-imports are significantly increased as well as the transit from North and Central China to the other provinces in Eastern China.

Figure 11-25 Net-exports (TWh) in 2050 from Central China provinces by destination (neg. origin) grid.



As has been mentioned above, Central China is at the receiving end of many of the exports especially from North, North-West and South China. Henan, the country's most populous country receives the lion's share of net-imports and followed by Hunan province.

Sichuan province is a net-export province supplying both other Central China provinces and well as sending power to Easter China through UHVDC lines. Chongqing receives a large proportion of its power supply from Sichuan, as does Hubei. In the Below 2 °C scenario there is also additional import to Hubei from North-West China. Jiangxi is also a net export province with imports from within Central China, East and South China.

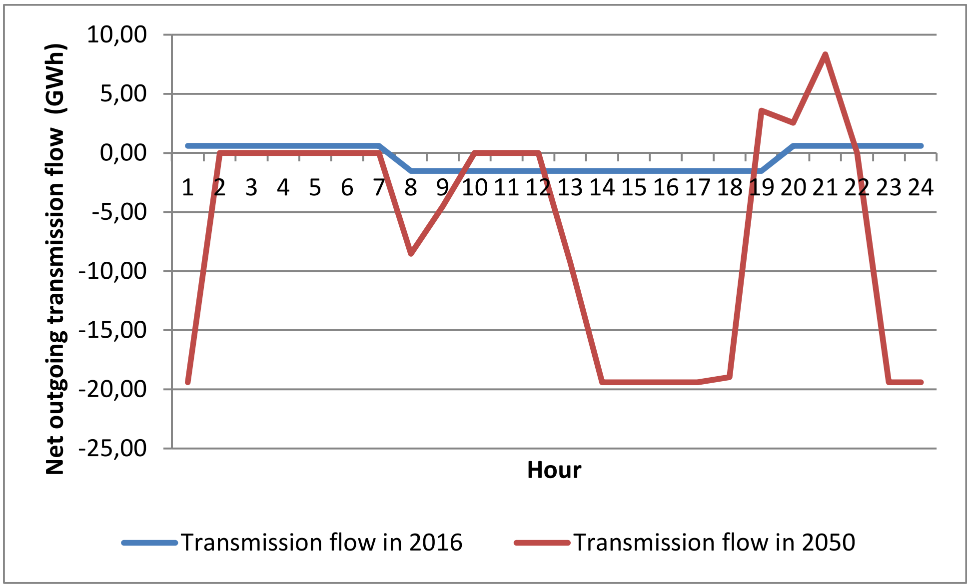
Operating interprovincial transmission lines flexibly

It is assumed in both scenarios, that the operation of interconnectors will shift from planned regime, to a flexible market based regime. As has been introduced previously, power markets are assumed to gradually expand, which motives towards the flexible use of the transmission system.

The results show that there are clear advantages of operating inter provincial transmission lines in a flexible way in terms of lower total system cost, lower emissions and better integration of RE. More detailed counterfactual simulations illustrating the value of this transition towards a more flexible regime are described in Part 3, but here an illustrative example is selected between two provinces with bidirectional power exchange.

Figure 11-26 shows the trade balance of an exemplary day in 2016 and 2050 from Henan to Hebei. In 2050, regional and provincial markets are fully integrated using interprovincial transmission lines in a flexible way. There is a clear difference of trading patterns and volumes between the two days due to the flexible use of transmission lines. Like shown in the chapters on grid development and market reform in Part 3 of this report, trading of electricity has clear benefits like a better integration of RE and lower electricity system cost.

Figure 11-26 Trade balance of one day in 2016 and 2050 (with flexible use of interprovincial transmission lines) from province Henan to Hebei



11.5 Electricity storage development

As variable renewable energy increases penetration in the scenarios, the economic viability of investments in new storage facilities increases. Meanwhile, the cost of more emerging storage technologies is projected to decrease over the scenario horizon.

In the scenarios, four categories of electricity storage are considered:

- Pumped storage – mature technology but naturally constrained with respect to where they can be deployed.
- Repurposed EV batteries – with expansion of the EV vehicle fleet a large volume of retired EV batteries could become available for repurposing as stationary storage
- Chemical storage – including Lithium Ion, Vanadium Flow, Sodium Sulphur, Lead carbon. Presently expensive, but the costs are coming done. Limited in terms of storage cycles, i.e. high variable costs. Flexible with respect to where they can be deployed.
- CAES – compressed air energy storage. Capital intensive and requiring special geological conditions. Low variable costs, but considerable loss in the storage cycle.

Note that additionally, CSP deployment is assumed to include storage, which is therefore an additional option.

Costs of storage technologies

Battery prices have declined significantly in recent years, they are still not at a level where they are cost competitive with other forms of storage, be it direct or indirect through load management. Currently, the investments costs are high, and the technology is at a stage where they have only a limited number of cycles.

The cost inputs and other relevant parameters in determining the overall effective costs for the storage options in the scenarios are displayed in Table 11-8.

Table 11-8 Energy Storage Parameters and Current Cost Estimates, 2015

	Specific investment costs (RMB/kWh)	PCS (RMB/kW)	Annual O&M cost as % of investment costs (%)	Conversion efficiency (%)	Lifetime (cycles)
Lithium-ion	1,950	650	3%	90%	2,000
VRB	4,225	1,300	3%	85%	13,000
Sodium sulphur	2,600	1,300	4%	80%	4,500
Lead carbon	1,300	650	3%	85%	1,000
Repurposed EV batteries	780	650	3%	90%	500
Pumped storage*	-	5,200	3%	78%	50 years
CAES*	-	11,400	3%	60%	40 years

** Cost per kW includes the full cost of generating and storage unit.*

Including both the battery costs and the Power Control System (PCS) investment costs used in the scenarios, the overall costs for the various technologies develop as displayed in Table 11-9.

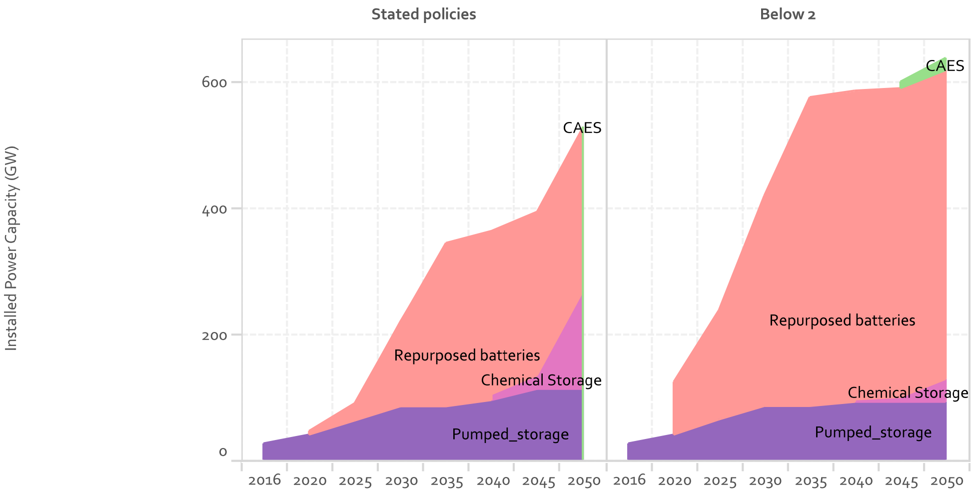
Table 11-9 Assumed development in investment costs in storage technologies. (RMB/kWh)

	2015	2020	2030	2050
Lithium Ion	2,110	1,810	1,330	715
Vanadium Flow	5,530	4,900	3,850	2,373
Sodium Sulphur	2,920	2,520	1,880	1,040
Lead carbon	1,460	1,340	1,120	780
Repurposed EV batteries	NA	720	530	390
Pumped-storage	650	660	680	715
CAES	1,300	1,100	910	610

Storage deployment

Pumped storage capacity reaches 40 GW by 2020 in accordance with the targets set in the 13th FYP for renewable energy. The capacity gradually expands further from this level reaching 112 GW in the state policies scenario and 92 GW in the Below to scenario. The development is outpaced by the deployment of repurposed batteries, which are abundant particularly in the Below 2 °C scenario, where the vehicle fleet is largest. New batteries are deployed from 2040 for bulk power balancing. However, the scenarios do not address how batteries could be deployed earlier at distribution level to alleviate local grid constraints, or to provide ancillary services other than active power balancing, which would be a likely situation. Compressed air energy storage is installed in in the late years in specific areas, which need a high utilisation balancing resource, but where there is limited or exhausted pumped storage potential.

Figure 11-27 Storage capacity (GW) and full load hour development in the two scenarios.



		2016	2020	2030	2040	2050	2016	2020	2030	2040	2050
Repurposed batteries	FLH Electricity		79	212	389	548		132	395	585	564
	Installed Power ..		6	133	259	259		83	333	489	489
Chemical Storage	FLH Electricity				37	159				51	234
	Installed Power ..				9	155				4	36
CAES	FLH Electricity					1.560					1.457
	Installed Power ..					2					19
Pumped_sto..	FLH Electricity	2.413	1.377	1.698	2.335	1.935	2.413	1.283	1.812	2.014	2.004
	Installed Power ..	26	40	85	95	112	26	40	85	92	92

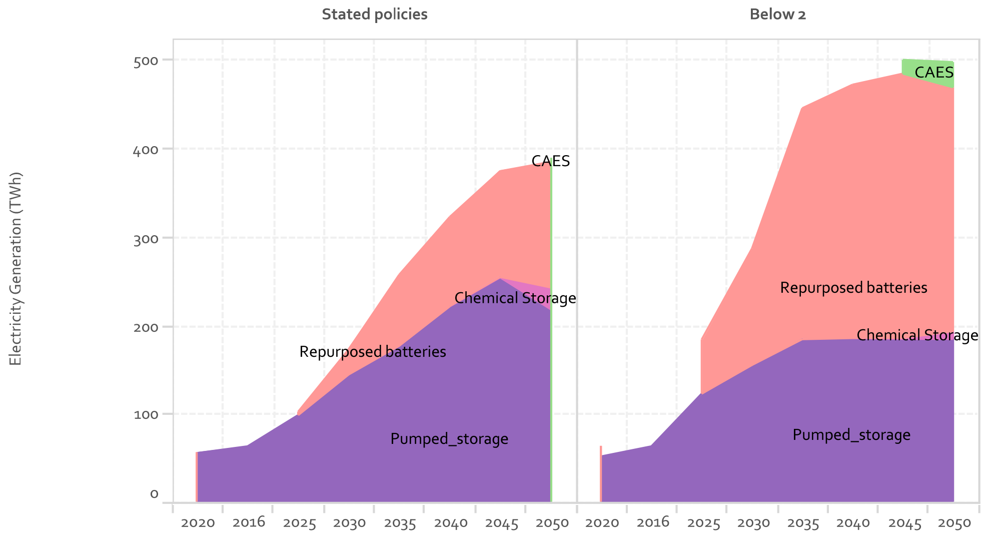
Pumped storage power stations provide significant flexible benefits and are presently an economical form of large-scale energy storage. The relatively low variable costs of operation and reasonably low cycle losses, ensures that the pumped storages have the highest full load hours of the technologies.

Chemical storages are now expensive due to the high cost and limited lifecycles of battery units. However, battery cost also shows a significant reduction trend over the recent years driven by the increasing battery demand from electric vehicle industry. Given the fast growth of EV fleet in the Below 2 °C scenario, the retired battery could also provide a large and presumably cheaper storage capacity as they commonly maintain 70-80% state of health (SOH) after their on-board life.

Repurposing of EV batteries in the energy system promises an economic opportunity to recover costs not only reduces costs for EV users, and provides a lower costs energy storage option for the power system, however, the cost data is highly uncertain. Additionally, the expected total number of cycles that the repurposed batteries can be operated is quite low from their when they are deployment as stationary storage as they are worn from previous use. The low cycles imply a high variable cost, representing the reinvestment in continuously maintaining the storage capacity of a battery stack.

Compressed air energy storage is capital intensive, but the operational costs are lower than for battery storage. Therefore, low capacity is developed but reasonably high utilisation for the capacity that is built. Compressed air energy storage is not developed to scale until 2050 in the Stated Policies scenario and 2045 in the Below 2 °C scenario. Regarding to the resource potential of energy storage, pump hydro storage may face a relatively clear resource cap of approximate 150 GW. We have not observed an official estimate of underground CAES storage potential (the technology focused in this research) from the open publications/media. The development of various chemical storages is generally less constrained by the resource shortage though short-term market imbalance of raw materials may cause cost variation.

Figure 11-28 Storage capacity (TWh) and full load hour development in the two scenarios.



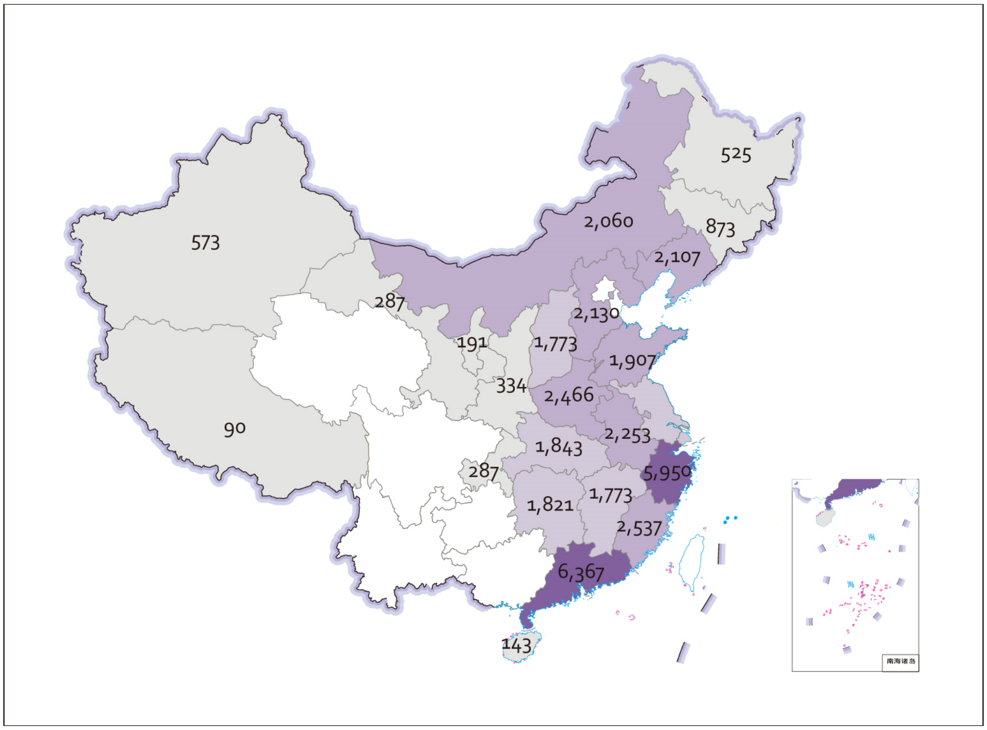
	2016	2020	2030	2040	2050	2016	2020	2030	2040	2050
Repurposed batteries		0	28	101	142		11	132	286	276
Chemical Storage				0	25				0	8
CAES					4					28
Pumped_storage	63	55	144	221	218	63	51	155	185	184

Despite the higher volume of installed battery storage capacity, including repurposed batteries, pumped storage, due to the higher full load hours sustains a larger role in the daily balancing of the system. The merit order of storage activation is first pumped storage, then CAES (once built) and finally battery storage.

Regional storage capacity deployment

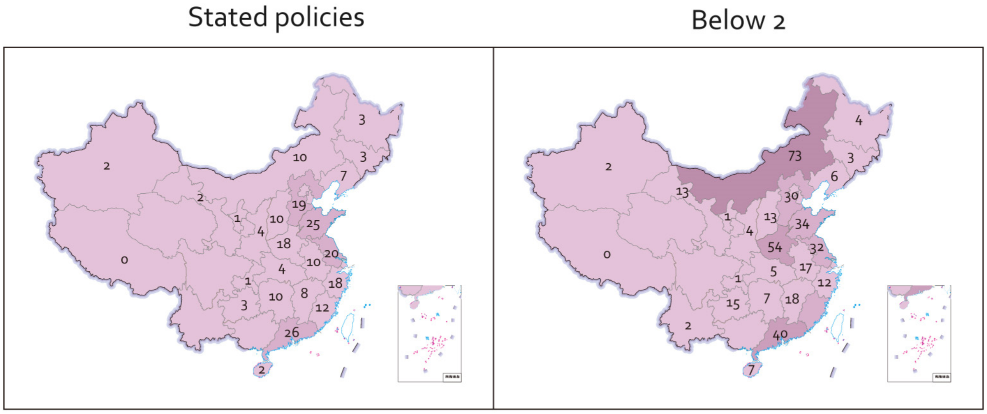
Until 2020, the deployment of pumped storage follows the detailed layout of the 13th FYP as shown in Figure 11-29, in both scenarios. The total of 40 GW of capacity is installed at national level.

Figure 11-29 Pumped storage capacity (MW) in 2020.



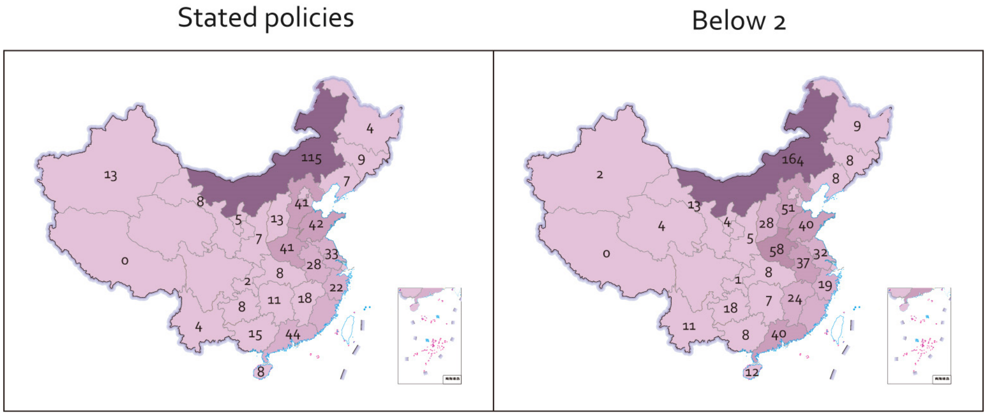
By 2030 the total installed electricity storage capacity has reached 218 GW in the Stated Policies scenario and 481 GW in the Below 2 °C scenario. A large portion of the incremental storage capacity in the Below 2 °C scenario is installed in Inner Mongolia, as well as in the coastal provinces such as Guangdong.

Figure 11-30 Storage capacity (GW) provincial deployment in the two scenarios in 2030.



By 2050 storage capacity reaches 528 GW in the Stated Policies scenario and 632 GW in the Below 2 °C scenario. Inner Mongolia, Henan, Jing-jin-ji, Shandong and Guangdong are the top deployers.

Figure 11-31 Storage capacity (GW) provincial deployment in the two scenarios in 2050.



By comparing of two scenarios, the Below 2 °C scenario has around 20% more storage capacity installation than the Stated Policies scenario. After 2030, the development pump hydro storage will be slowed down by the resource cap despite its low cost per energy unit of discharge. Repurposed battery will serve an important storage role in the Below 2 °C scenario due to the fast EV market growth and the low cost assumption. Should this cost assumption not be realisable, there remains several other options for storage provision which could be deployed alternatively. Ceteris paribus, cost of storage would however be higher, and therefore the total role of storage as a flexibility provider could be lower.

11.6 System balancing

The hourly verifications confirmed that the power system can balance at hourly level given generation, storage and demand response capacity mix. By a model, this is done efficiently, with only very limited curtailment of VRE output. This result is contingent on several assumptions regarding the economic and institutional framework for the power system. These assumptions include:

- holistic planning of deployment and use of power supply, transmission, storage and demand response capabilities;
- provision of efficient incentives for asset owners to develop and operate in line with overall system objectives, herein specifically the assumption that the power reform will develop an efficient power market;
- Institutional barriers are removed and that operational approaches and perspectives are modified and adjusted to conform to the reality of power system with High RE penetration, and particularly high penetration of VRE sources.

As the capacity mix evolves over time, the role and importance of different technologies to ensure that the system can be constantly in balance. In the following sections, one week of the hourly simulation is presented for 2020, 2030 and 2050. The same week, week 11, is used for each illustration where the generation and consumption sides are illustrated. Finally, since looking at the power consumption and generation patterns for the whole system, does not show the operation and value of the use of transmission, and example is provided to show how transmission, i.e. imports and exports, to and from Guangdong province interacts to create the balance with the local generation and power consumption.

Short-term (2020)

Power consumption at national level by 2020 basically follows the exogenous load curve introduced in Section 11.3 on Figure . The penetration of EVs in the system is still insignificant form the perspective of the overall power system. Storages load at night, for discharge mainly the peak demand periods. The volume of storage is slightly higher in the Below 2 °C scenario than in the Stated Policies scenario. Power to heat creating an additional electricity demand. Broadly speaking, however, the demand side is fixed by consumption patterns, and therefore regulation must be carried out predominantly on the generation side.

Figure 11-32 National power consumption during week 11 in 2020 in the two scenarios (GW).

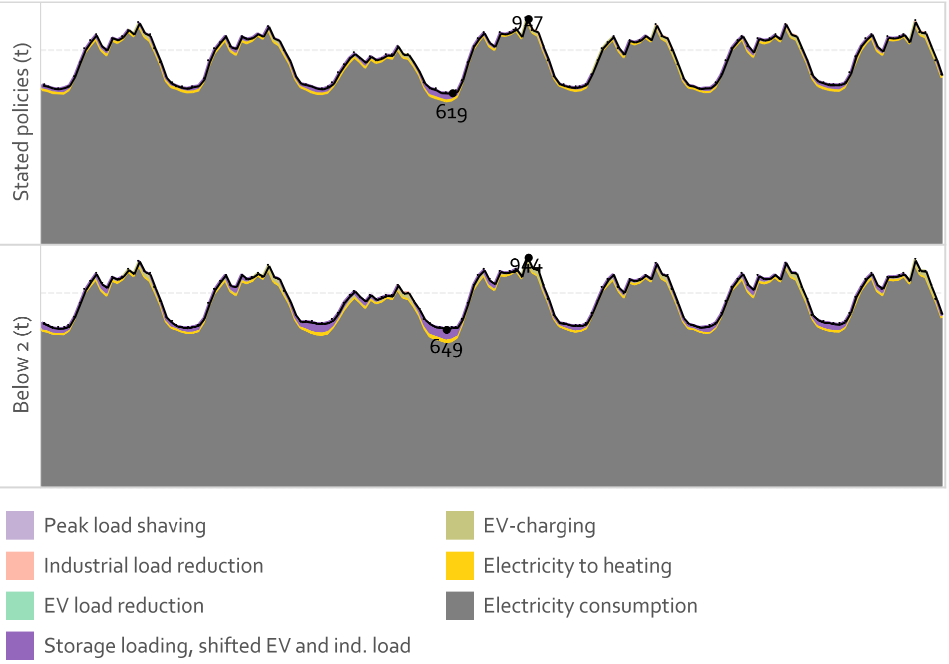
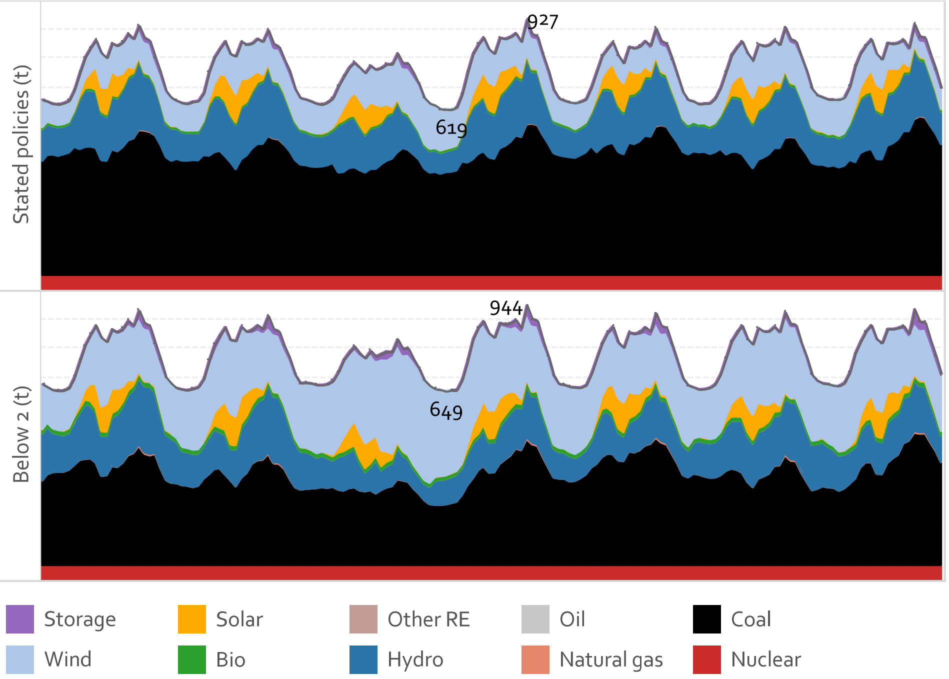


Figure 11-33 National power generation week 11 in 2020 in the two scenarios (GW).



Coal is the primary source of generation and flexibility. By 2020, the coal fleet, especially the coal-fired CHP plants have to a large extent been retrofitted. This is especially the case in the Below 2 °C scenario. Further details on the coal flexibility retrofit analysis is found in the chapter dedicated to thermal power plant flexibility in Part 3 of this report. In the Below 2 °C scenario it is evident that the penetration of wind power is increased compared to the Stated Policies scenario, whereas the solar penetration is not much higher, as was shown previously. It is also evident that the variability of the wind power generation in the whole country is less than the variability of solar, which is naturally only during daylight hours. The additional VRE generation results in less coal-fired generation and more ramping of coal. Also, there is more storage discharge, primarily in the evening peak.

Medium-term (2030)

The demand curve does not change very much from 2020 to 2030 and neither does the ratio between the peak load and base load. From Figure 11-34 it is evident that by 2030, electric vehicle charging starts to be shown on a system level that smart charging is deployed to smooth the charging load produced by the similar plug-in patterns of car owners. As some people may come home before sun sets when solar panels still produce power, some electric vehicles are charged around 17 o'clock, while other cars are charged during low load hours after midnight and before people are off to work on the second day, and some are charged around noon at work when solar panels produce a lot.

On figures illustrating hourly power consumption in this section the black line indicates the adjusted power consumption, including from 'normal' load, power to heat (district heating), EV load after adjustment from smart charging, storage loading but not discharging (generation) and adjustments from demand response from peak shaving and load shifting. Hence this line indicates the load which must be satisfied by generation as indicated on these figures.

For EVs, the teal colour labelled 'EV load reduction' indicates EV charging not carried out at the indicated time due to smart charging. The green label 'EV-charging indicates charging of EVs which is not reduced. Finally, the additional charging of EV's resulting from the aforementioned load reduction is bundled together with energy storage loading and increased industrial load from load shifting and shown in purple. 'Industrial load reduction' separately indicates where load is shifted from.

Figure 11-34 National power consumption during week 11 in 2030 in the two scenarios (GW).

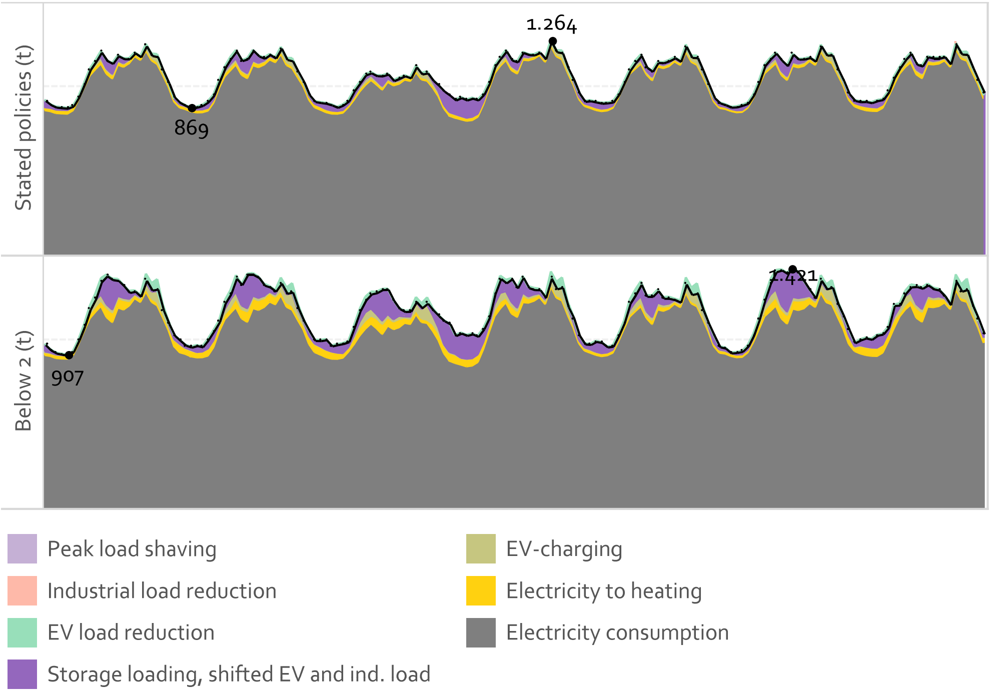
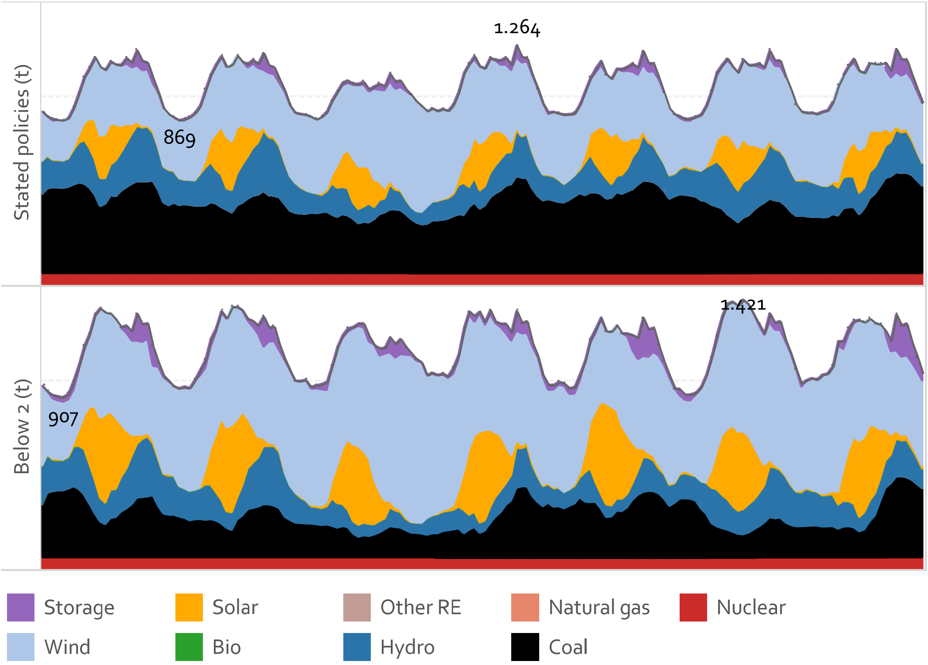


Figure 11-35 Power generation during week 11 in 2030 in the two scenarios (GW).



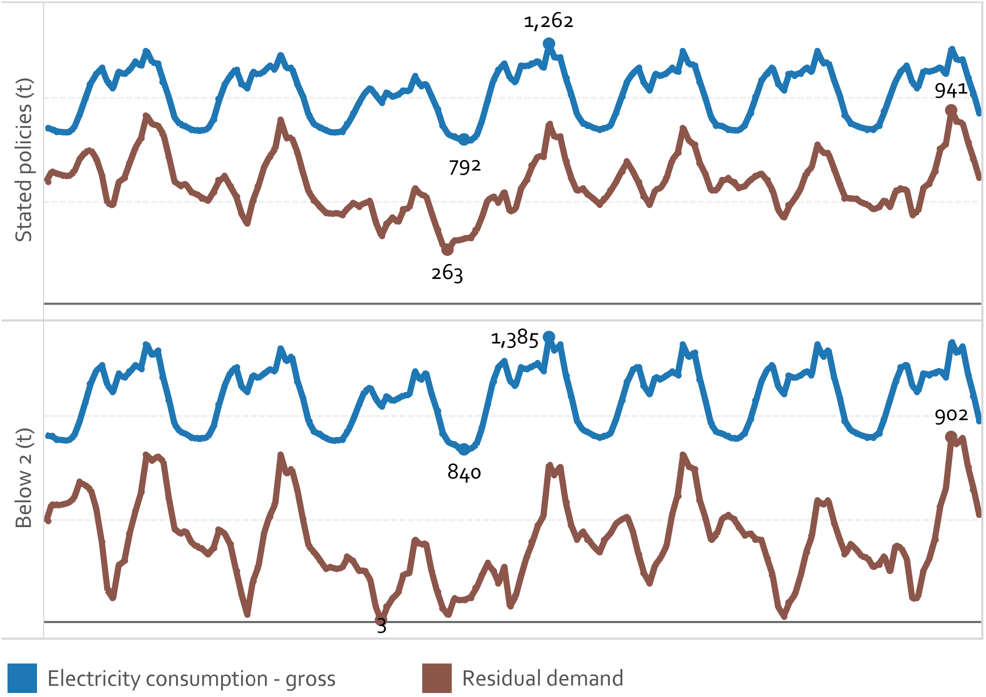
In the Below 2 °C scenario, to allow a higher penetration of renewables in the whole energy system, electricity-to-heat technologies are well deployed, which consume power in the range of 50-70 GW in the whole country during the heating seasons. Storage also starts to play an important role in the system to accommodate more renewables, which consume power when wind and solar produce more power than demanded and produce power when wind or solar produce less than demanded on hourly/daily basis. It is noted in Figure 11-34 that new peak loads may be introduced by high power production from local renewables when storage can charge. As smart charging of electric vehicles, storage, and demand response being introduced into the system as sources for providing flexibility on demand side, load patterns may vary depending on the inflexible generation profiles. With the coordination of smart charging, demand response, local storage and local renewable generation, net load may be further smoothed to integrate renewables locally as much as possible, and help increasing the efficiency of distribution network.

Heat storage is also an important element on integrating renewables locally. As heat can be more easily stored but more difficult to transported compared with electricity. Heat storage may help on providing flexibility on power supply side, e.g., centralized heat storage attached to CHPs, and on power demand side, e.g., hot water tanks at home. CHPs and electricity-to-heat elements as interfaces between heat and electricity system can be utilized for accommodating renewables and increase the share of renewable in primary energy consumption to a large extent. In addition, seasonal heat storage may help solving energy shift in a long period for dealing with the seasonal mismatch between supply and demand.

In the Stated Policies scenario, thermal power plants and nuclear together provide half of the load as shown on Figure 11-35. Nuclear produces constant power at its available capacity as it is costly to regulate and technically challenging. Flexible thermal power plants (i.e., flexible coal CHP and natural gas plants) together with hydro serves as the major flexible source in the system to balance the mismatch between variable RE production and demand, especially during later afternoon when solar production drops while the demand is still high. Figure 11-36 shows the regulation challenge on the generation side, but subtracting the variable renewable generation from the power consumption curve.

In the Below 2 °C scenario, the share of coal power plants is reduced significantly, while wind becomes the major source in the system on providing electricity. Pumped hydro and repurposed batteries are two major types of storage used in the system for short-term balancing. Larger fluctuations of flexible coal CHP and hydro production indicate that they take heavier responsibility on balancing the system, especially during the early evening, the production of hydro can ramp up from 126 GW to 214 GW in a few hours and then back to 172 GW. During the peak hour, renewables provide more than 75% of the overall load in the whole country.

Figure 11-36 Net-load curve, Electricity consumption minus VRE generation for week 11 in 2030.



Long-term (2050)

In both scenarios, the charging profile of electric vehicles will have a significant impact on the consumption patterns. Smart charging is essential for the power system as the results show that instant charging may result much higher peak approx. 450-550 GW during the evening added onto the evening peak, which may result in congestions and voltage issues in power distribution grids.

Electricity-to-heat is well deployed in the Stated Policies scenario, and produces approx. 100-150 GWh power to heat, which is slightly lower during the day (due to solar heating and higher temperature) and higher at night. However, in the Below 2 °C scenario, since RE heating is more effective to use and electrification in transport and industrial sector demands electricity, electricity-to-heat fades out from the power demand. The strong requirements for the decarbonization of electricity, implies that marginal electricity consumption must be 100% decarbonized and be able to cover the marginal integration costs to be cost effective.

Storage in both scenarios play important roles as a flexible source to shift power around, and reshape consumption patterns.

Figure 11-37 National power consumption during week 11 in 2050 in the two scenarios (GW).

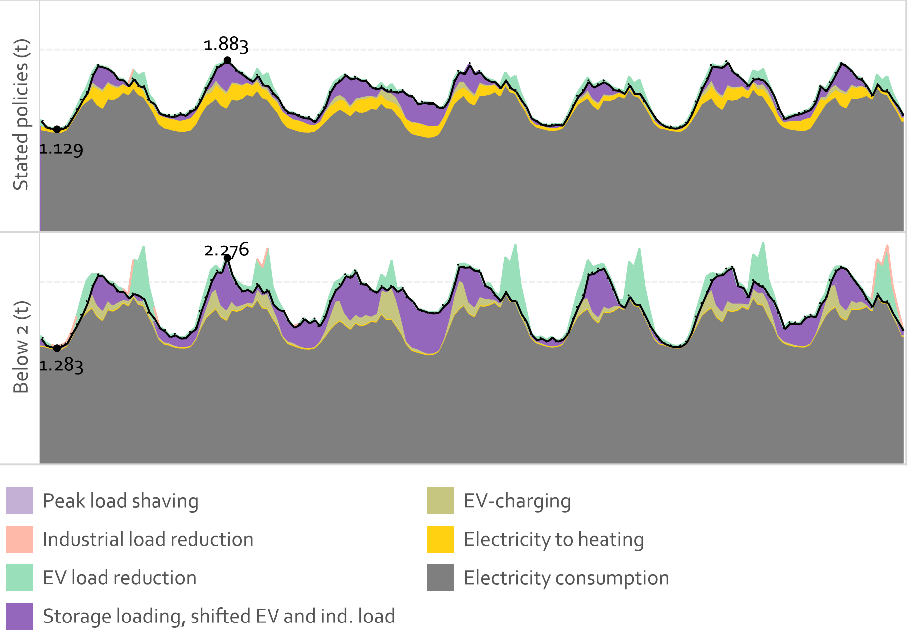
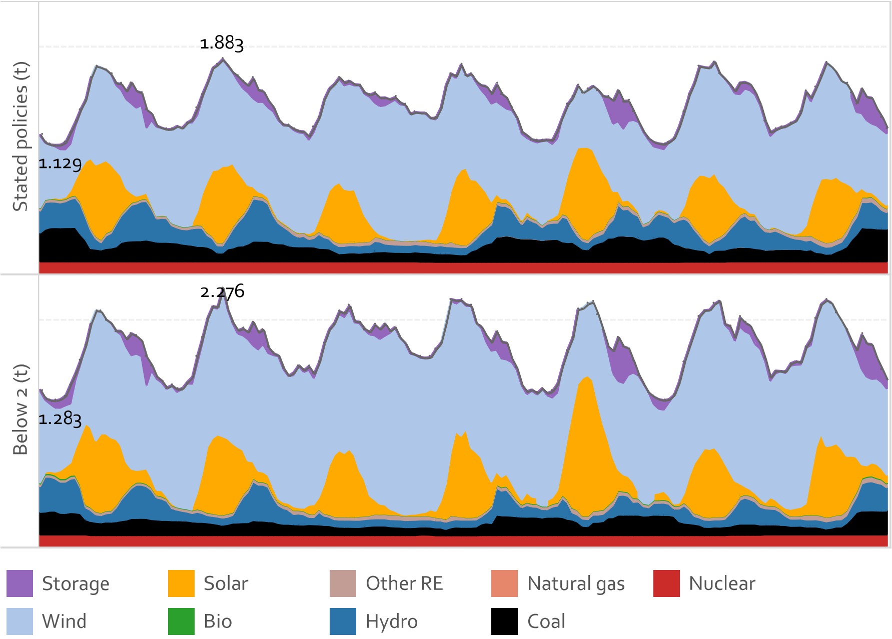


Figure 11-38 Power generation during week 11 in 2050 in the two scenarios (GW).



In both scenarios, inflexible coal power plants and natural gas almost fade out from the supply curves. Nuclear continues to provide power constantly during the whole week. Biomass replaces coal and serves as the energy resource in CHPs. Power production of these flexible CHPs and hydro plants fluctuates against wind and solar to balance the system. Compared to scenarios in 2030, the average running hours of CHPs and hydro plants are significantly reduced. Wind is the largest sources in both scenarios. Solar becomes the second largest in the Below 2 °C scenario, and produces more power than coal fired plants. Storage provides power with the residual load is the highest.

Figure 11-39 Net-load curve, Electricity consumption minus VRE generation for week 11 in 2050.

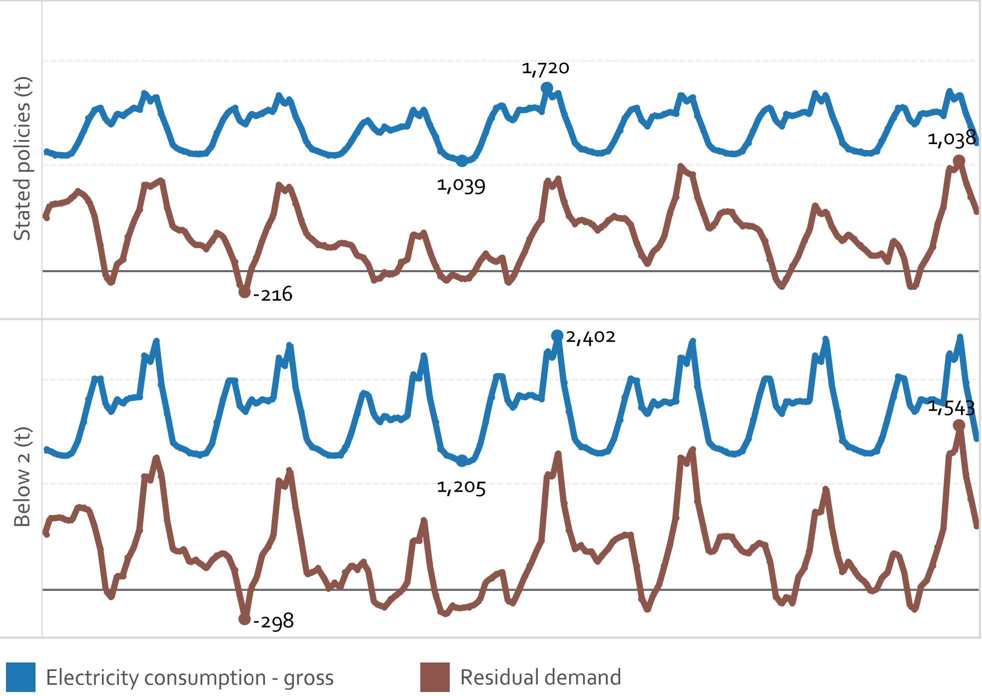


Figure 11-39 demonstrates definitively that the concept of 'baseload' is rendered meaningless in the power system by 2050 in both scenarios. As the national load profile net of VRE generation is often negative, there is baseload is not a service which carries a premium in the system. Conversely, technologies which are unable to regulate generation add costs to the system. Flexibility and dispatchability, however, are premium products and the market mechanisms to encourage their deployment and efficient operation are critical for operating this system. Furthermore, in large parts of the system, the traditional provides of ancillary services are displaced from the market. It is therefore paramount to develop mechanisms to ensure that the ancillary services are provided by the new sources of generation and to supplement these with additional components, e.g. in the grid, storage and on the demand side.

Transmission

Looking at the national level supply and demand provides crucial insight into the supply demand and balancing situation in the future Chinese power system. However, at this scale the implications from use of transmission is not apparent. In the modelling, each of the power systems 32 electrical regions maintains a supply and demand balance at every timestep and transmission, i.e. import and export flows, are crucial to the balance within the provinces. To illustrate this, Guangdong province is highlighted as an example of the role of transmission in the medium and long-term in the following. Guangdong is a major consuming province and a net importer throughout each of the scenarios, but thorough strong interconnections it also becomes a transition hub for flexibility.

Medium-term (2030)

Figure 11-40 and Figure 11-41 show the demand and supply side respectively for Guangdong in week 24 – a summer week - similar to the figures in the previous section but with a portion of either demand or supply covered by power import or export with interprovincial transmission lines. However, exports are included on the demand side (Figure 11-40) and imports are included on the supply side (Figure 11-41). From the figures it is obvious that the system balance is highly pendent on interaction with connected provinces, both in terms of bulk energy supply and in terms of flexibility provision.

Figure 11-40 Guangdong demand and exports week 24 in 2030 (GW).

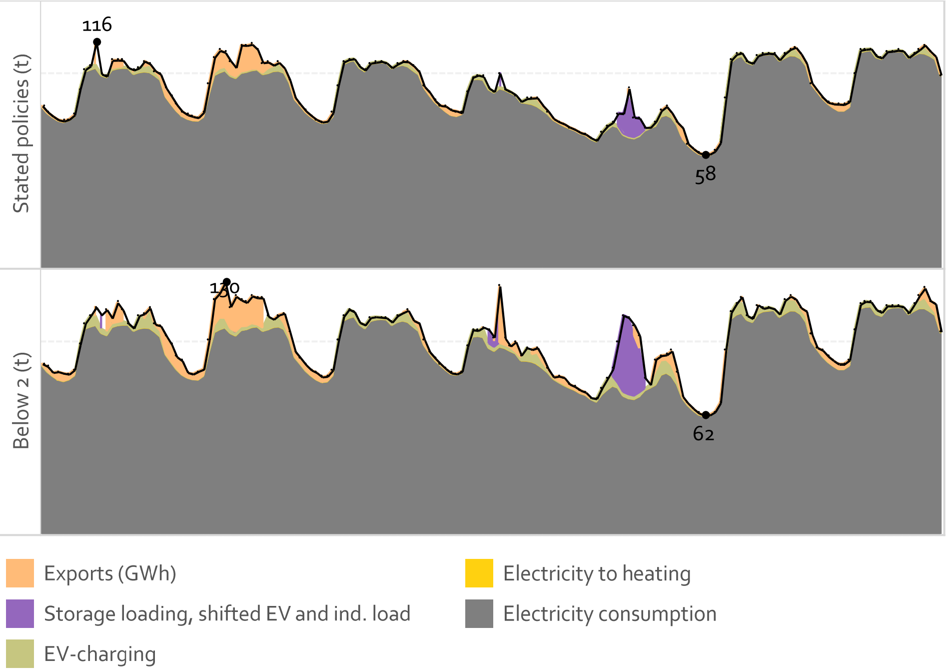
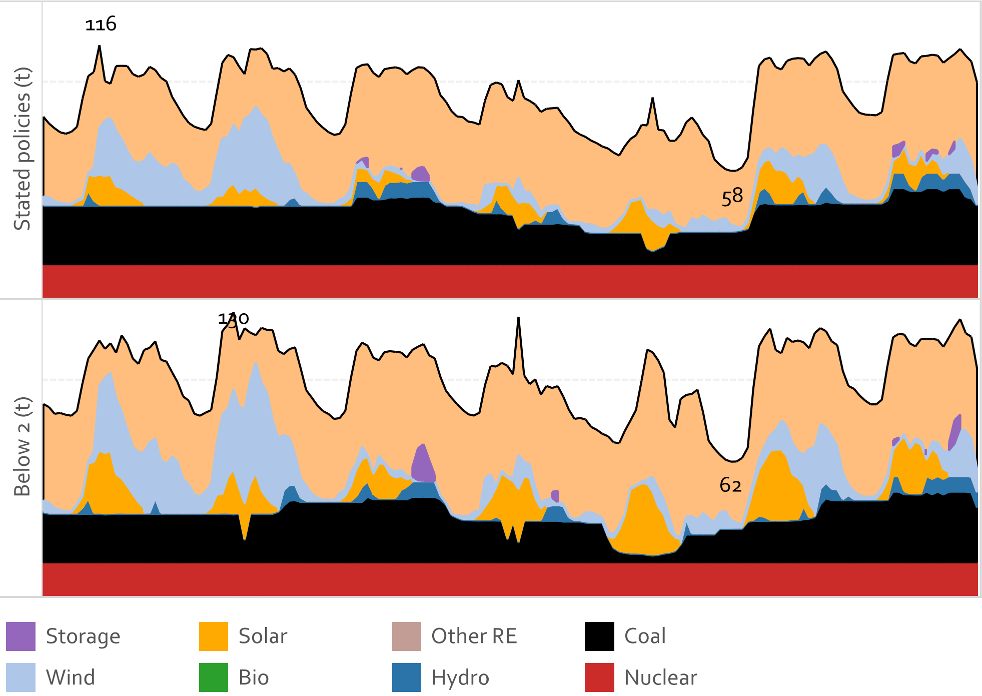


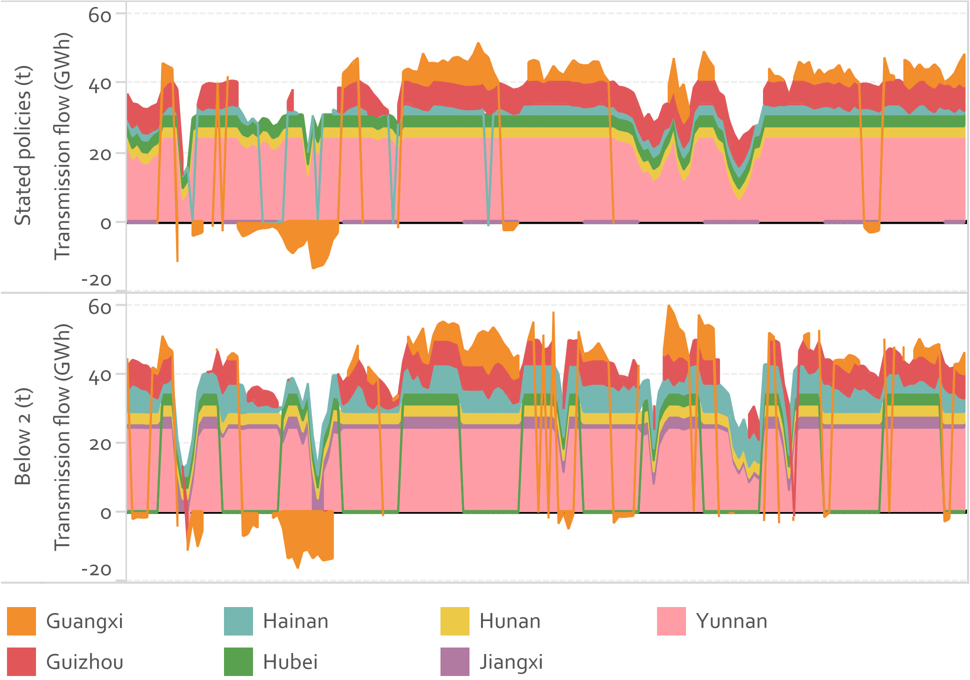
Figure 11-41 Guangdong generation and import (light orange) week 24 in 2030 (GW).



The imports and exports are unpacked by origin and destination in Figure 11-42, where the flows are shown as net-imports from the perspective of Guangdong province. Some transmission lines start to deploy flexible dispatch of power transmission on the lines between provinces and regions. Therefore, fluctuations are visible on transmission lines to maintain best allocation of resources, some of which are renewables. With tight capacity limits, i.e., congestions may be found on the transmission lines, and prices are different on two sides of the line, power is delivered at the level which the capacity allows.

The power supply in Guangdong cannot provide enough power locally especially during the summer. It imports power from Yunnan, Hunan, Hubei, Guizhou, and Guangxi and exchange power with Hainan in the Stated Policies scenario. Yunnan supplies the largest portion, which is mainly from wind and hydro. It is suggested from the figure that the capacity of the transmission line between Yunnan and Guangdong limits the power transmission, and the cost of power in Yunnan is cheaper than in Guangdong. In 2030 the transmission flows between Southern grid provinces are market based, whereas the transmission flows to other provinces use fixed schedules.

Figure 11-42 Guangdong interprovincial net-imports week 24 in 2030 (GW).



In the Below 2 °C scenario, Guangdong starts to import from Hainan and Jiangxi, because more renewables are installed in these two provinces, and electrification of different sectors in Guangdong demand more electricity than can be supplied locally.

In the winter, the load in Guangdong is less and while still is a net-import position, there are more flows also going out of Guangdong. Week 50 demand (Figure 11.43) and supply (Figure 11-44) charts. Note that in the morning of the second day, wind and solar generation peaks simultaneously in addition to having very large imports. Locally, the charging on EVs and DR and storages is maximized to boost consumption. Hence, Guangdong is using the opportunity to balance the both local and remote generation, through its large consumption and storage flexibility.

Figure 11-43 Guangdong consumption and exports week 50 in 2030 (GW).

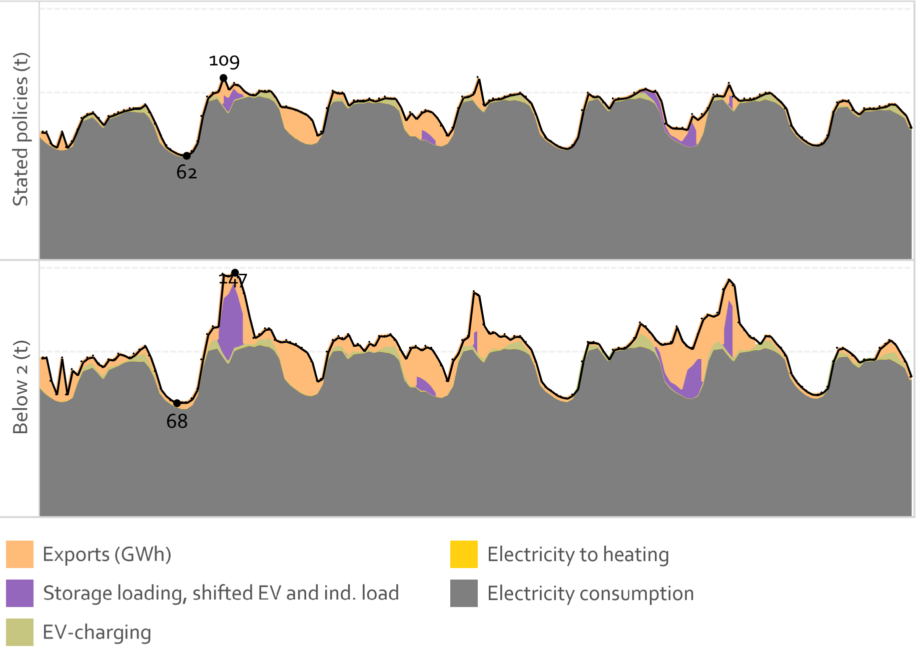


Figure 11-44 Guangdong supply and import week 50 in 2030 in the two scenarios (GW).

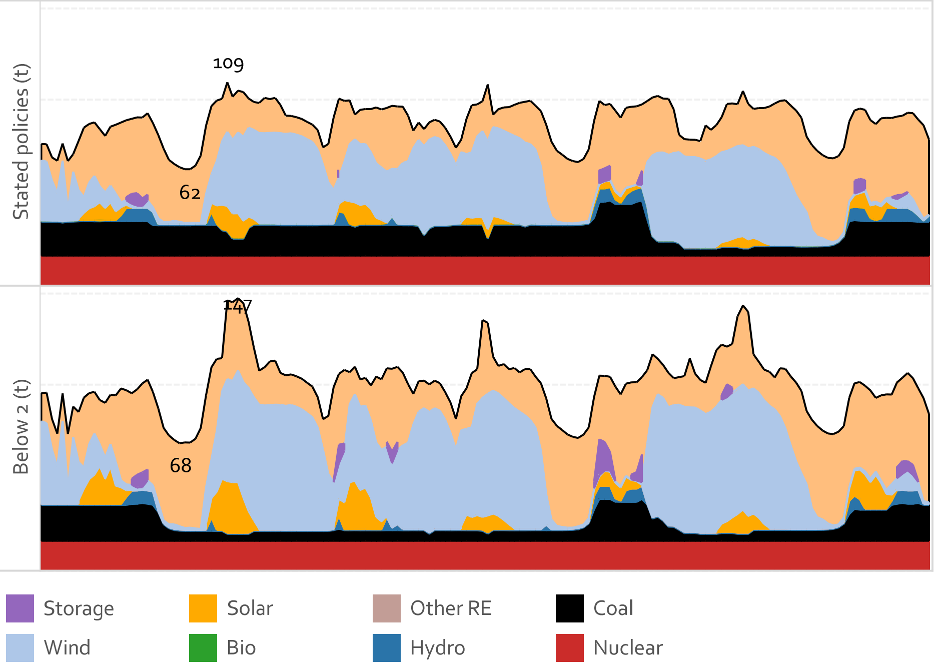
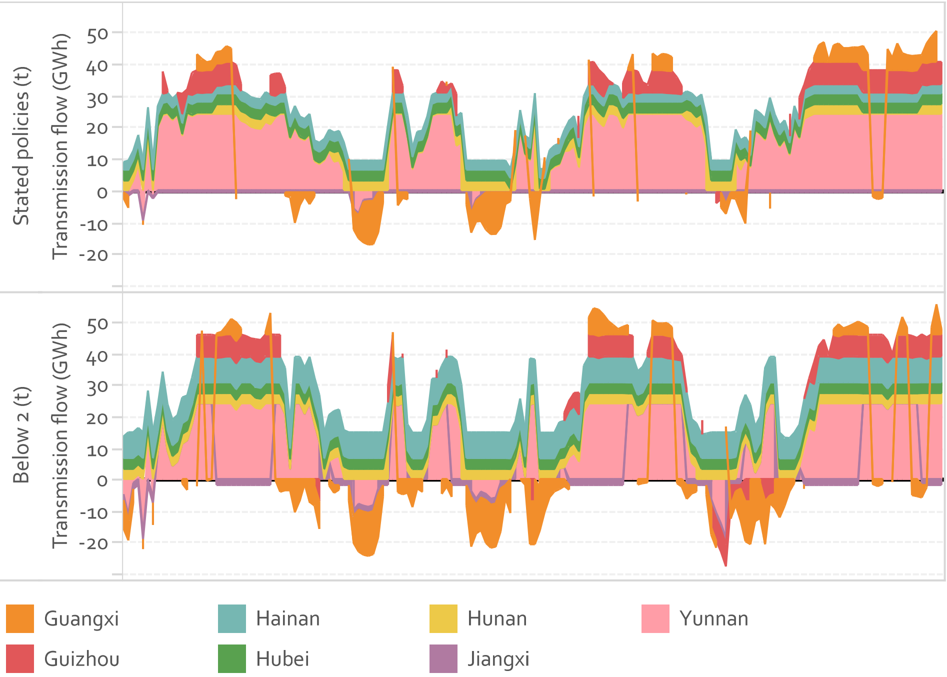
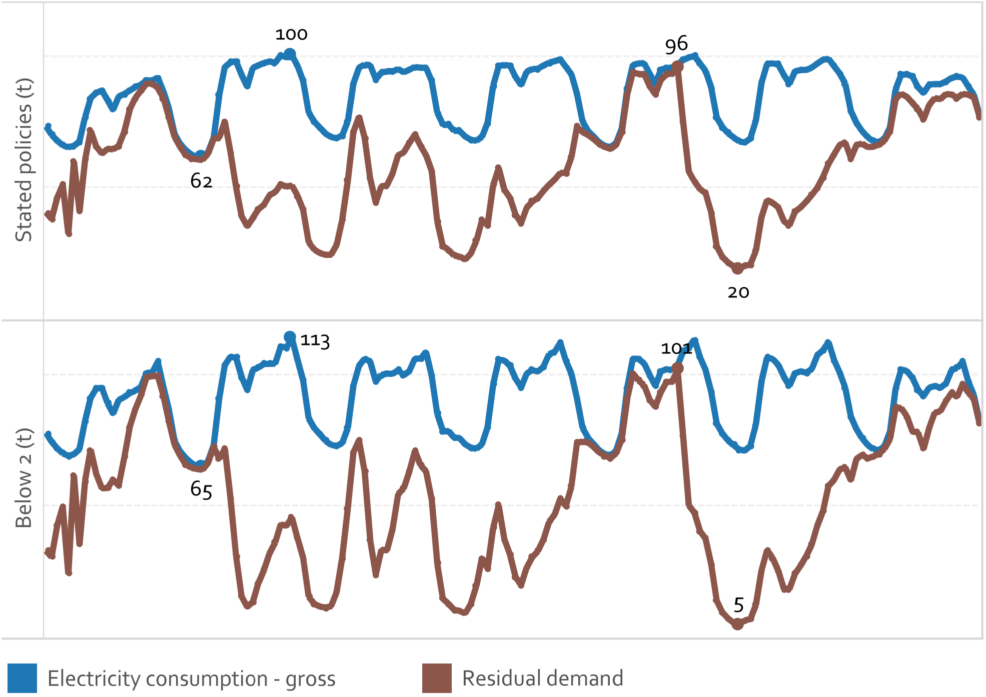


Figure 11-45 Guangdong interprovincial net-imports week 50 in 2030 (GW).



Overall, the general pattern of trade flows with Guangdong is the same as in the summer, with Guangdong primarily being the destination of flows, however, there are more exceptions to this rule in the winter. The power flow is more often in the direction of Guangxi, and the flows also reverse back to Yunnan. Hainan, Hubei and Hunan all send steady flows towards Guangdong. Note that by the power market assumptions, flows with Hunan, Hubei, Jiangxi still follow the rigid two step flow patterns. Jiangxi is mostly an export destination for power from Guangdong, which could however, also be considered as transit. Guizhou mostly provides support during the peak times, by which should be understood the net-load peaks as illustrated on Figure 11-46.

Figure 11-46 Net-load curve, Electricity consumption minus VRE for Guangdong, week 50 in 2050.



Long-term (2050)

Transmission lines are expanded, i.e., larger capacity is deployed for power transmission between provinces and regions. Thus, higher fluctuations can be expected from the results. Moreover, the nationally integrated market allows highly flexible power trading. Physical constraints of transmission lines are the only constraints that limit the interprovincial power exchange.

In Guangdong, as the growth of local capacity does not keep pace with the increasing electrical demand and more power needs to be imported from outside in 2050. Compared with the transmission situation in 2030, power flow becomes more fluctuant. Hainan becomes the second largest province that export power to Guangdong. Fujian exchanges power with Guangdong from on occasion depending on the power production of renewables in these two provinces, so as Hubei and Hunan. In the winter, as wind power in Hainan need to be exported and the hydro in Yunnan is not as abundant as in other seasons, Guangdong imports more power from Hainan rather than from Yunnan.

Interprovincial power exchange relies both on robust and flexible operation of interprovincial transmission lines, especially those long-distance HVDC lines, and on well-established market mechanisms that allows flexible power exchange among provinces.

Figure 11-47 Guangdong consumption and exports week 24 in 2050 (GW).

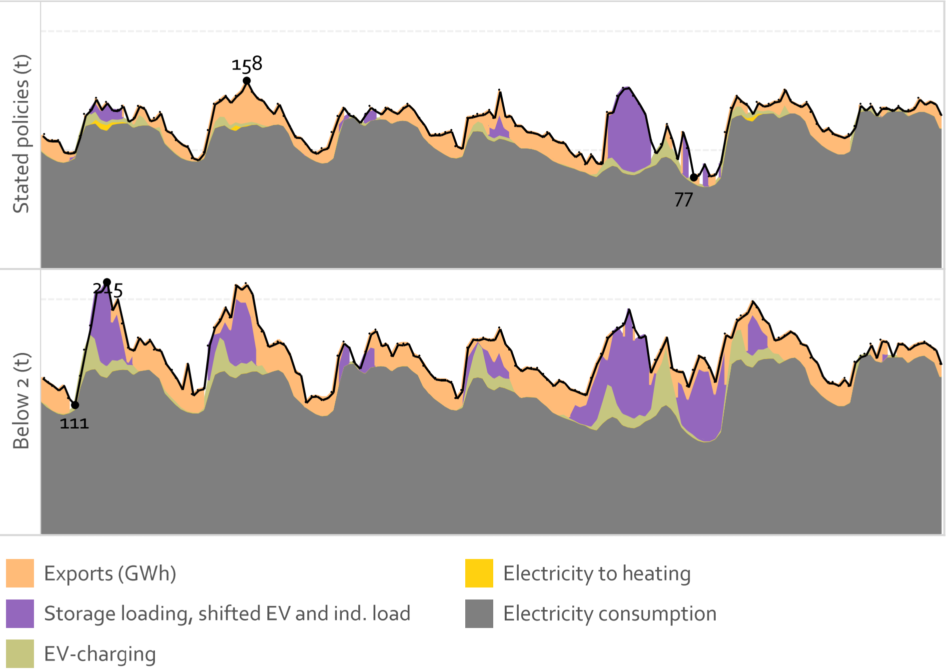


Figure 11-4 8Generation and import in Guangdong week 24 in 2050 (GW).

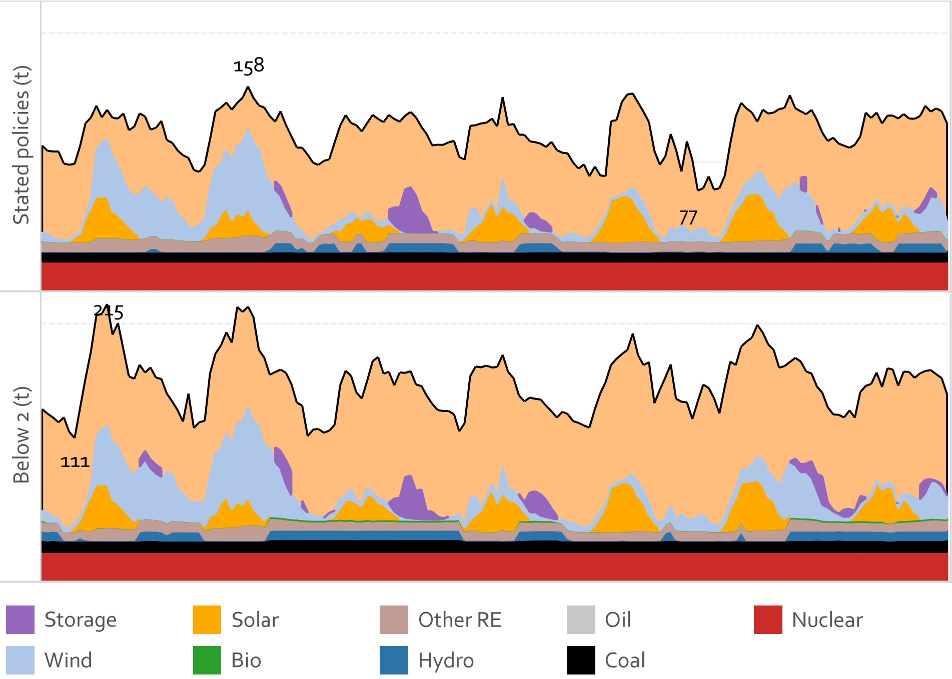


Figure 11-49 Guangdong consumption and exports week 50 in 2050 (GW).

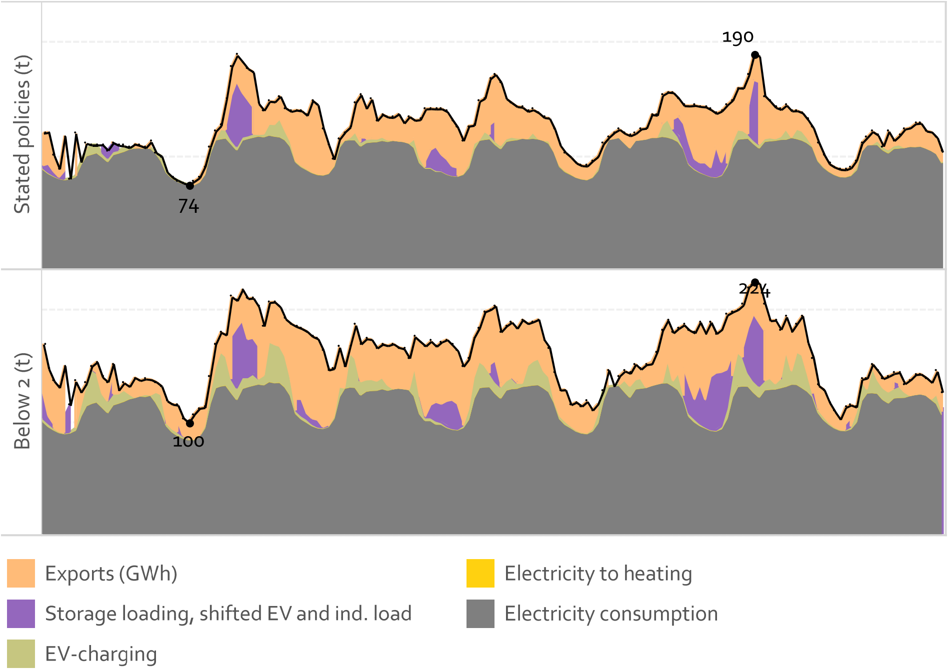


Figure 11-50 Generation and import in Guangdong week 50 in 2050 (GW).

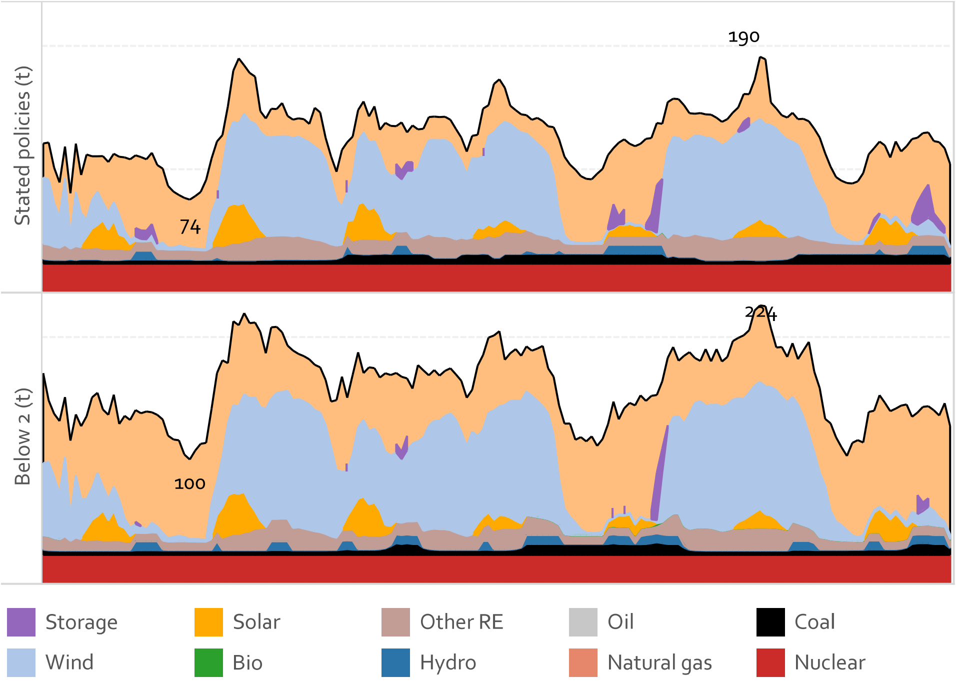


Figure 11-51 Guangdong interprovincial net-imports week 24 in 2050 (GW).

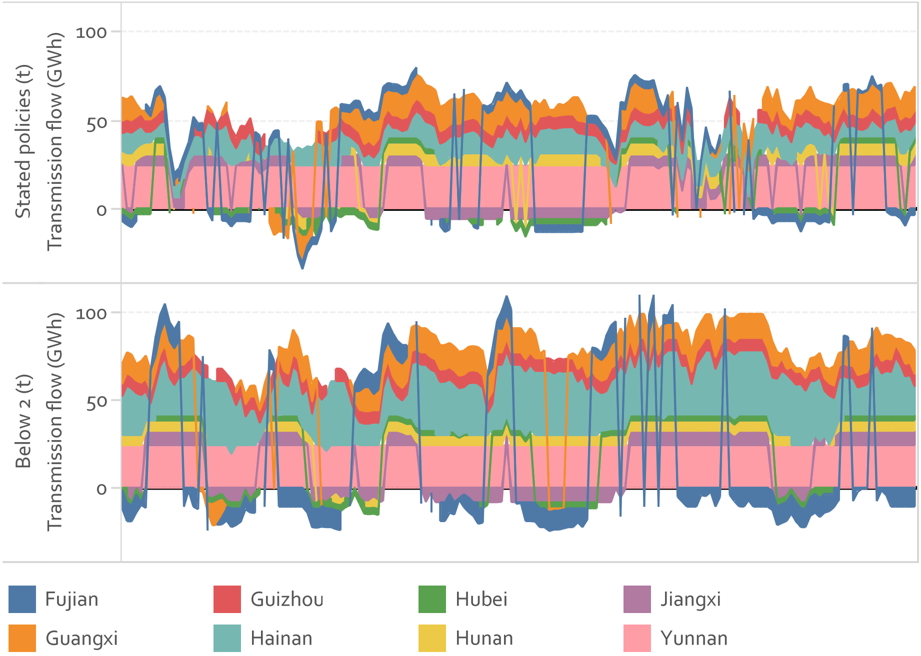


Figure 11-52 Guangdong interprovincial net-imports week 50 in 2050 (GW).

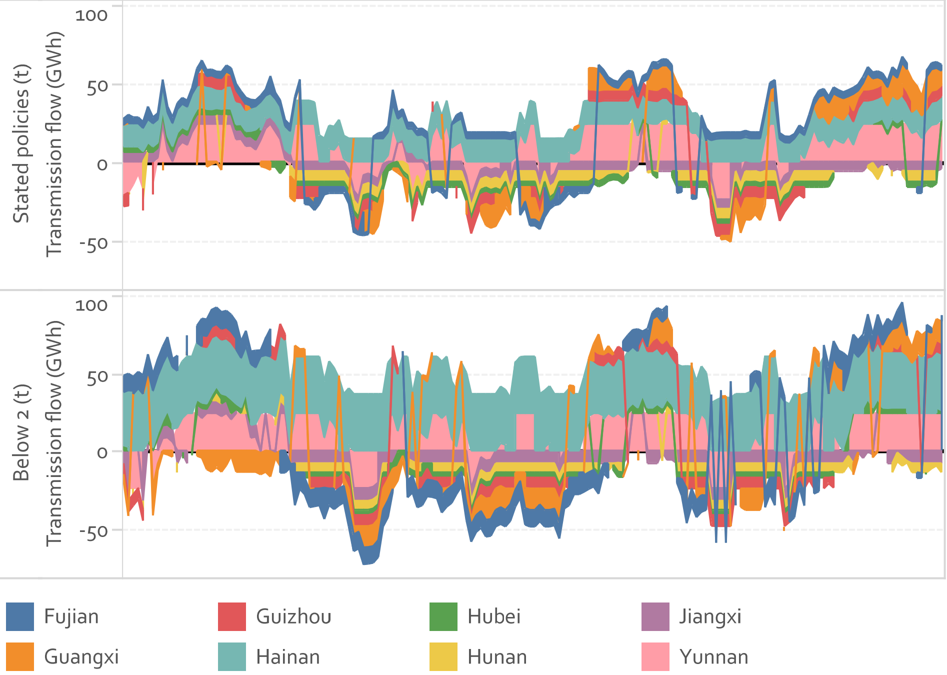
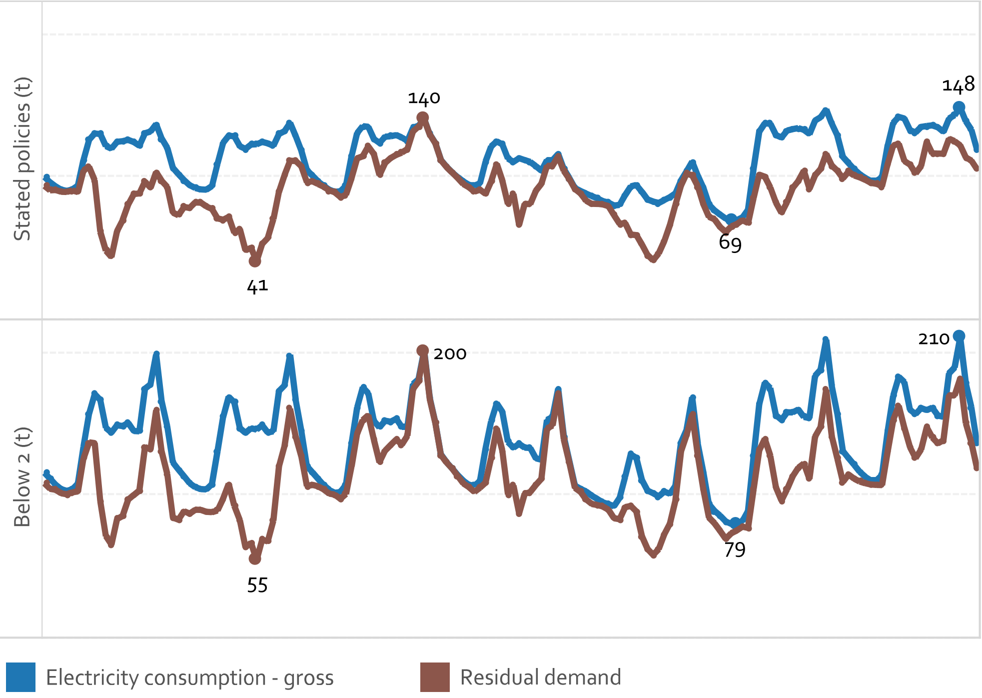


Figure 11-53 Guangdong net-load curve, Electricity consumption minus VRE generation for week 24 in 2050.



11.7 Summary

This chapter has provided description of the power system transformation, which takes place in the two scenarios, at a considerable level of detail, by successively outlining transformations in terms of generation, consumption, grid and storage. It is finalised by illustrating how the scenarios' power system can succeed in maintaining the balance between supply and demand down to an hourly level, first at an aggregated level and subsequently looking at specific provincial system, therein capturing also the implication of transmission for maintaining the system balance locally. Based on the simulation results a further 31 stories of power system balancing could be presented.

Main aspects regarding of the power system transformation have already been presented in Section 11.1, and the further impacts in context of the energy system transformation has been described in Chapter 9. Essentially, the storylines of the scenarios, from the power systems perspective, highlight impending paradigm shifts which the power industry faces. Market reform, policy reform and not least mindset reform is at the centre of the transformation in the power sector. All stakeholders, from generation companies and grid companies, policy makers and consumers, will have to undergo a mindset change to realise either of the visions encompassed in the scenarios.

12 Macroeconomic consequences of the energy transition

This Chapter describes the analysis of the macroeconomic consequences of the energy transition taking place in the two scenarios. The analysis relies on the Computerised General Equilibrium model, which is soft-linked to the EDO and LEAP models upon which the previous chapters analyses are based.

The chapter summarizes the macroeconomic developments of main indicators.

1. Investment activity, including the impact of accelerated RE investments in the power sector.
2. The development of RE power generation in terms of direct output value and value added, as well as the development of non-RE power generation.
3. The stimulated indirect output value and value added from RE and non-RE power sectors.
4. Shifts in employment between industries considered, also looking both the increase employment from RE power and related upstream sectors as well as the decline in employment from non-RE power sectors and their upstream related sectors.

In addition to the key assumptions introduced in Chapter 8, section 12.1 introduces the overall economic development assumptions, which provide the foundation for the analyses.

12.1 Economic assumption

China aims to achieve its long-term strategy of modernization by the year 2050, as described in Part 1. The per capita GDP shall reach the level of a moderately developed country. Due to successful reforms the driving force of economy is more sustainable and economic structure will improve. Overall GDP growth is expected to gradually slow down, but still maintain levels that will ensure high-income status by 2050. All the main drivers of growth evolve gradually. With the beneficial impact of opening the economy and integration into the world economy expected to phase down, with China moving closer to the technological frontier, and with declining potential to remove distortions, productivity growth edges down over time, although to a still high level by regional standards. Finally, the contribution of capital accumulation to growth also declines but remains sizable. GDP will grow from 40 trillion RMB in 2010 to 282 trillion RMB in 2050, equivalent to an annual growth rate of 4.8%. The per capita GDP grows from 4,500 USD in 2010 to 30,000 USD in 2050, equivalent also to an annual growth rate of roughly 4.8%.

Over a 20-year horizon, this pathway also sees significant changes in the structure of the economy, supporting a reduction of economic, social, environmental, and external imbalances. The importance of industry declines and that of the service sector rises. The share of primary industry will drop from 8.1% in 2010 to 2.6% in 2050. On the other hand, the share of secondary industry will decrease from 45% in 2010 to 24% in 2050, and the share of tertiary industry will increase from 46.6% in 2010 to 73% in 2050.

This pathway features significantly lower investment, hence a smaller contribution from capital accumulation. Investment as a share of GDP declines over time. This ratio trends down by 21.6%-points to a more sustainable 24% in 2050, well below both current levels and levels under any alternative "on past trends" scenario. Despite lower investment, the current account surplus gradually declines over time, as a share of GDP, easing external imbalances. However, this effect would be broadly offset by still high productivity growth, driven by factors such as more reallocation of labour (both across firms and from rural to urban areas), more financial sector reforms, better corporate governance, fewer distortions and barriers to services sector activities, more research and development (R&D), and more development of human capital.

The economy creates more urban jobs and, as a result, more rural-urban migration, higher rural productivity and income, and less urban-rural inequality. More urbanization stimulates the service industry, including through spending patterns of urban residents. The share of employment in agriculture falls to 12.5% in 2050. This decline works to support the growth of labour productivity in agriculture, hence income growth in that sector. The decrease in the productivity gap between agriculture and the other sectors underlies lower urban-rural income inequality. The economy will be less commodity and energy intensive. That is because it has less industry and, within industry, less heavy and dirty industry, in large part because of better pricing of energy, commodities, and environmental degradation. The share of consumption in GDP rises from 40.9% in 2010 to 68% in 2050, reversing the past steady decline. Reforms that encourage urban job creation and greater upward pressure on wages boost the share of wages and household income in GDP, increasing the role of household consumption. Government consumption rises on the back of increasing social spending and spending on operations and maintenance.

Table 12-1 Overview of macroeconomic development in the Stated Policies scenario

Trillion RMB	2015	2020	2030	2050
GDP	60	84	146	282
Investment	25	33	52	67
Consumption	28	42	80	192
Government	8	11	19	37
Output	173	240	411	729
Export	21	29	47	80
Import	20	28	46	79

Note: *Since the CGE model uses constant price in base year rather than current price in future years, the relationship that GDP = Consumption + Investment + Government spending + Exports - Imports only holds in the base year but not in future years.*

Development until 2030 source: *World Bank, 2013. China 2050 Building a Modern, Harmonious, and Creative Society.*

12.2 Investment activity

Significant investment is required to achieve the transition of the physical energy system, described in the two scenarios. By 2050, annual investments in developing renewable energy increase at a moderate rate to over 3950 billion RMB in the Stated Policies scenario and 6000 billion RMB in the Below 2°C scenario. Investments in the wind and solar in the Below 2°C scenario reach around 4390 and 860 billion RMB, respectively.

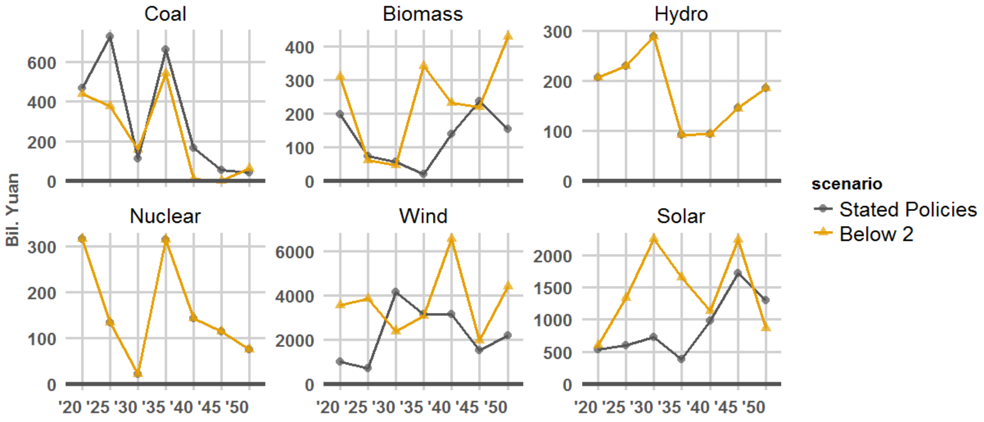
This investment pattern brings about significant impacts on the economic system. Conceptually there are three levels of direct and indirect economic effects.

First, we find significant expansion in the renewable power sectors.

Second, investment in RE development would create considerable demand for investment goods and benefit the related upstream industrial chain consequently.

Third, other industries could lose, especially those related to conventional energy supply. The net effects on the whole economy are unknown without taking account of aggregated positive and negative effects comprehensively.

Figure 12-1 Total investment in RE from EDO model



12.3 Economic impacts of RE development

Three indicators are used to measure the macroeconomic impact from RE development in the scenarios namely: the aggregated output value, value added, and employment. These indicators' impact is evaluated in terms of both the direct stimulating effects in the RE power industries, and the indirect impact in the supply chain. Secondly, the impact of the displaced fossil-fuel industry is considered, also in terms for the direct implications for the fossil fuel-fired power generation, as well as for the upstream industries in the supply chain.

Direct economic impacts on the RE power sector

The increasing installed capacity of renewable power leads to drastic increase in the economic output of the renewable power sectors. The monetary value added of renewable power sectors in 2010 and 2015 were quite small, about 0.22 trillion RMB (equivalent to 0.54% of GDP) and 0.6 trillion RMB (just under 1% of GDP), respectively.

In the Stated Policies scenario, the value added of aggregated renewable power sectors increases to 5.9 trillion RMB (2.2% share of Chinas GDP) in 2050. This is equivalent to an annualized growth rate of 6.79% from 2015 to 2050, which is higher than the average annual GDP growth rate of 4.32% in the same timeframe.

Furthermore, in the Below 2°C scenario, wind and solar energy attract much more investment. As a result, the value added of all renewable power sectors reaches 7.65 trillion RMB in 2050, accounting for 2.93% of the GDP. Similarly, the annual growth rate of RE value added (7.6%) in the Below 2°C scenario is significantly higher than the GDP growth rate (4.3%) during the 2015-2050 timeframe.

The output of the aggregated renewable power sectors increases to 12.6 trillion Yuan by 2050, from 9.7 trillion Yuan in the Stated Policies scenario. Table shows the breakdown of the aggregated output and value added in the Below 2 °C scenario, and highlights the weight of the wind and solar industries in particular.

Table 12-2 2050 output of RE power by 2050 in the Below 2°C scenario (trillion RMB)

RE POWER SOURCE	AGGREGATED OUTPUT (TRILLION RMB)	VALUE ADDED (TRILLION RMB)
HYDRO	1.4	0.85
WIND	7.8	4.7
SOLAR	3.1	1.89
BIOMASS	0.34	0.21
TOTAL RE POWER	**12.6**	**7.65**

The renewable power sectors will become a mainstay industry if it these growth rates are realised. The evolution of direct output from RE power development is illustrated on Figure , and the evolution of value added from RE power is illustrated on figure.

Figure 12-2 Direct value added of renewable power sectors until 2050 (2010 prices)

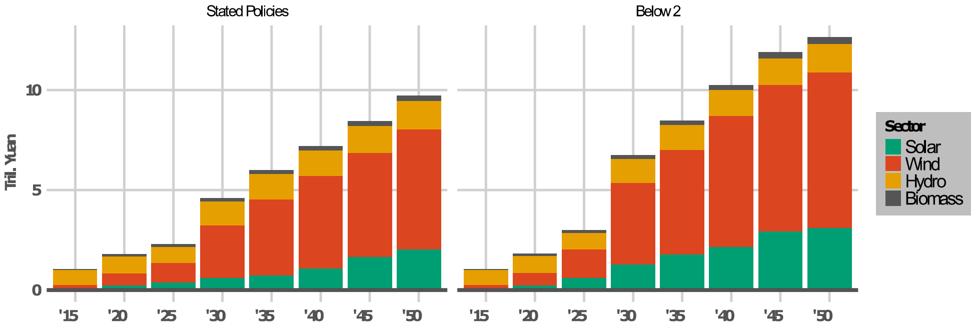
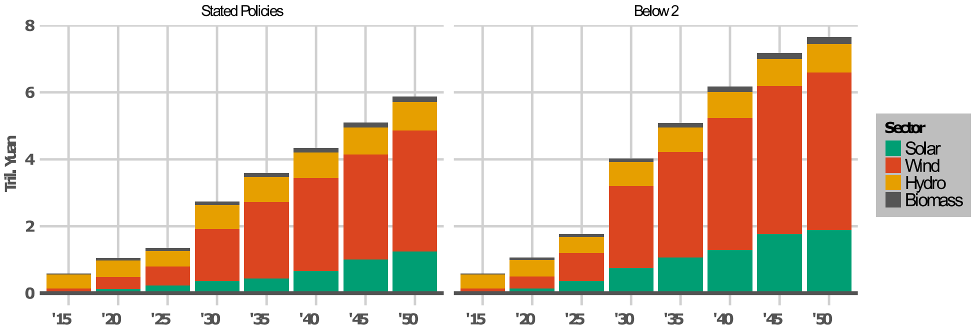


Figure 12-3 Direct output value of renewable power sectors until 2050 (2010 prices)



From 2015 level, direct value added in the RE power industry increases by 10 times in the Stated policies scenario and 13 times in the Below 2°C scenario. In comparison, the total GDP in the scenarios expands by 4.7 times, meaning that the RE industry accumulated direct value-added growth rate outpaces the societal growth by a factor of 2.1 from 2015-2050 in the Stated policies scenario and 2.8 in the Below 2°C scenario.

Indirect economic impacts of RE development: industry stimulation

Expanded investment in RE development is required for the purchase of special equipment such as wind turbines and silicon plates, an expenditure different from that incurred in constructing fossil-fired power plants. This investment stimulates output in the upstream industries, creating green growth points and employment. The output value has two components:

- Investment goods required by the capital input in RE technologies
- Intermediate inputs required for the maintenance of RE power generation units

Wind and solar power have greater stimulation effects than hydro in 2050 in both scenarios. In the Stated Policies scenario, the indirect output stimulated in other sectors is 12.1 trillion RMB in 2050 is and indirect value added is 3.8 trillion RMB, which implies an additional contribution to GDP of 1.4%. In the Below 2°C scenario, the total indirect output value of other sectors stimulated by renewable energy are 17.4 trillion RMB. Thus, renewable energy induces a further 5.5 trillion RMB of value added, accounting an additional contribution of 2.0% of the GDP in the Below 2 °C scenario.

Figure 12-4 Stimulating effect of RE development on value added in other sectors from 2015 to 2050

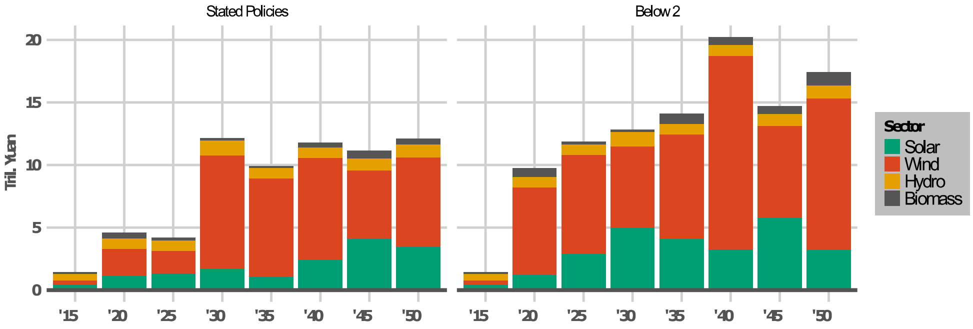
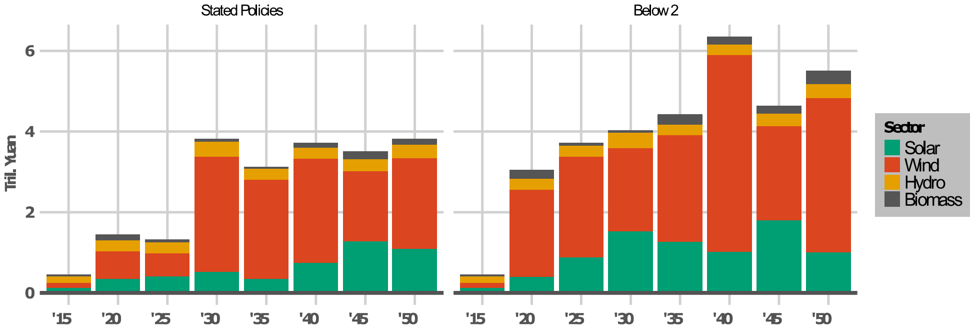


Figure 12-5 Stimulating effect of RE development on output in other sectors from 2015 to 2050



From Figure 12-6 and Figure 12-7 it can be deduced that the four sectors deriving the most benefit from RE development are machinery, transport, service, and electronic equipment since capital input in RE development requires more products and services from machinery, service, R&D, and electronics than from other sectors.

Figure 12-6 Stimulating effect of RE development on outputs employment of other sectors in 2050

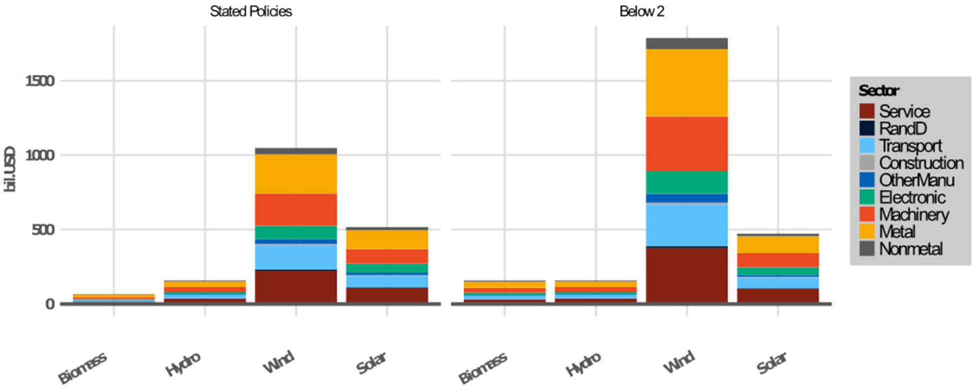
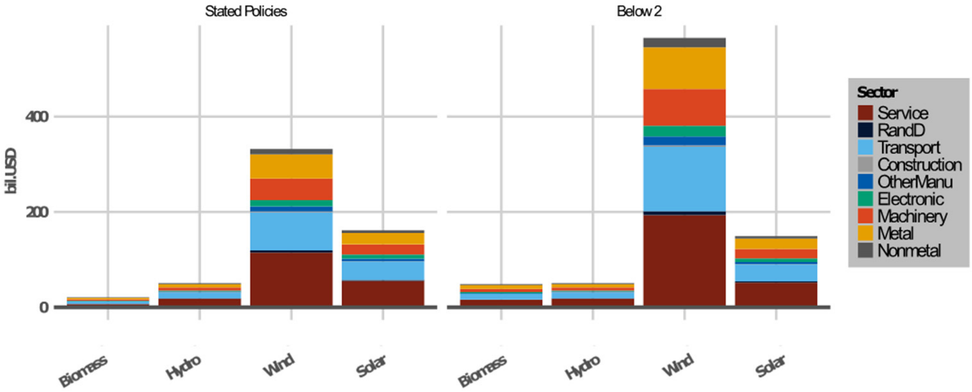


Figure 12-7 Stimulating effect of RE development on value added in other sectors in 2050



Macroeconomic impacts of non-renewable power supply

The stimulation of renewable energy development implies that RE power accounts for an increasing share of the macroeconomy. Meanwhile, the many other sectors, especially those related to conventional energy supply chain, will decline in relative as well as absolute economic standing. Substitution of fossil-fired power generation will lead to direct and indirect reductions in sectors related to non-RE power supply.

The following indicates the scale of these effects on due to decrease in coal- and gas-fired and increase nuclear power generation resulting from the modelling. In both scenarios, output value of the fossil power generation will decline, while nuclear power expands, as one would expect from the significant change in the physical output from these technologies. In 2050 of Stated Policies scenario, the output value of fossil power generation would be 0.86 trillion RMB and nuclear grows to 0.8 trillion RMB. In 2050 of Below 2°C scenario, output from fossil-generation further reduced by to 0.54 trillion RMB.

As the nuclear deployment is the same in the two scenarios, the economic output is 0.8 trillion as in the Stated Policies scenario. The development of these direct effects on output from coal, gas and nuclear power is illustrated on Figure 12-8. Direct value added in these sectors drops to 0.27 trillion RMB for fossil power generation in the Stated Policies scenario and 0.17 trillion RMB in the Below 2 °C scenario, while nuclear increases to 0.48 trillion RMB in 2050 in both scenarios.

Figure 12-8 Direct output of non-RE power in 2050 (2010 price)

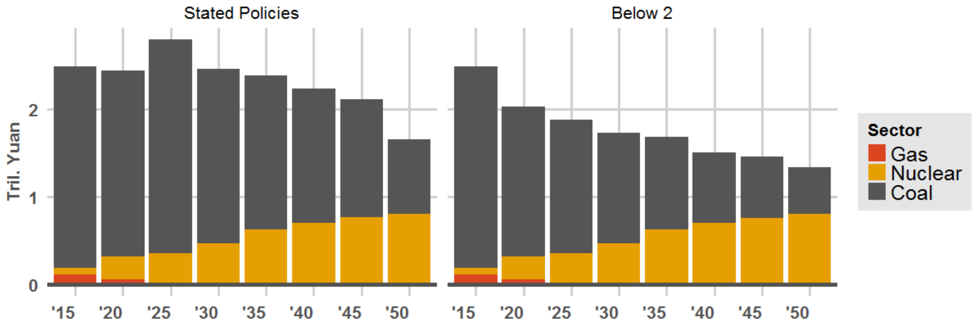
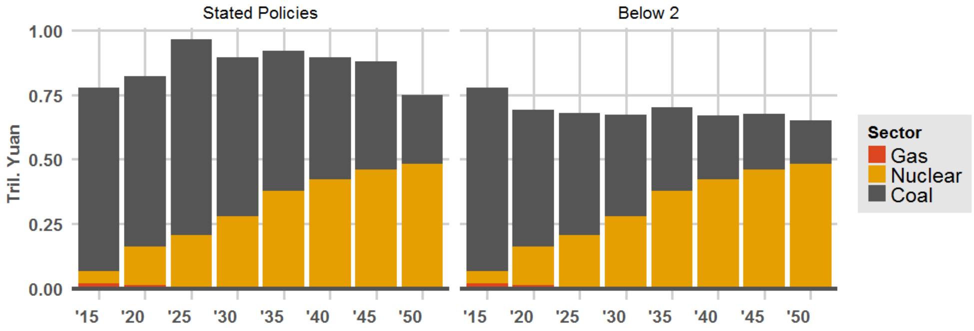


Figure 12-9 Direct value added of non-RE power in 2050 (2010 price)



The indirect economic effects will also change correspondingly. As Figure 12-10 and Figure 12-11 show, in 2050 of Stated Policies scenario, the total stimulated output and value added reduces from coal power generation is reduced to 2.19 trillion RMB and 0.72 trillion RMB respectively, while by 2050 in the Below 2°C scenario, these indicators drop to 0.53 trillion RMB and 0.18 trillion RMB, respectively. Meanwhile, the simulating effect of indirect output from nuclear increases to 0.57 trillion RMB and indirect value added increases to 0.18 trillion RMB in both scenarios.

Figure 12-10 Stimulating effect of non-RE power on output of other sectors from 2010 to 2050

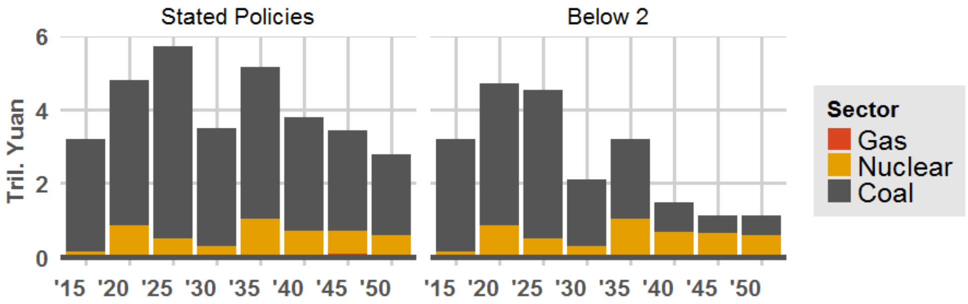
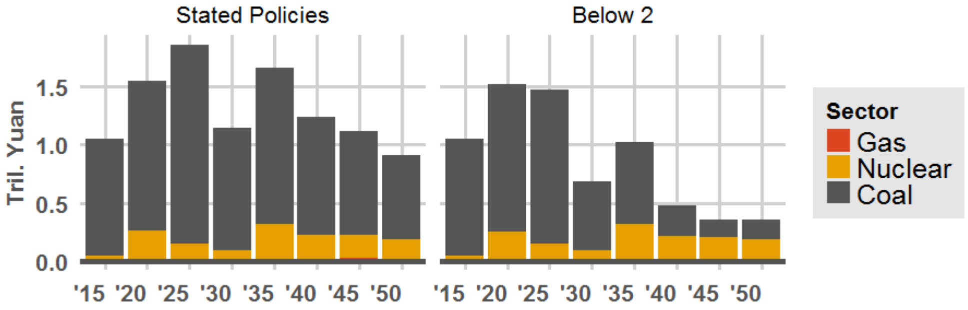


Figure 12-11 Stimulating effect of non-RE power on output of other sectors from 2010 to 2050



As seen on Figure 12-12 and Figure 12-13, the stimulated output of coal-fired power generation drops from 2.19 trillion RMB in Stated Policies scenario to 0.53 trillion RMB in Below 2 °C scenario in 2050. Correspondingly, the value added of the upstream industries drops from 0.72 trillion RMB to 0.18 trillion RMB. The most affected industries are metal production, machinery, transport and services. By contrast, industries related to nuclear power generation are not affected between both scenarios, the output and value added of which remain 0.57 and 0.18 trillion RMB, respectively.

Figure 12-12 Stimulating effect of non-RE power on output of other sectors in 2050

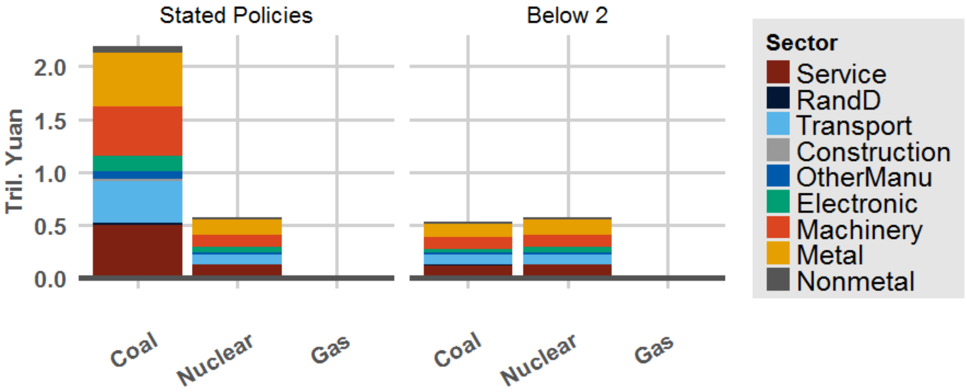
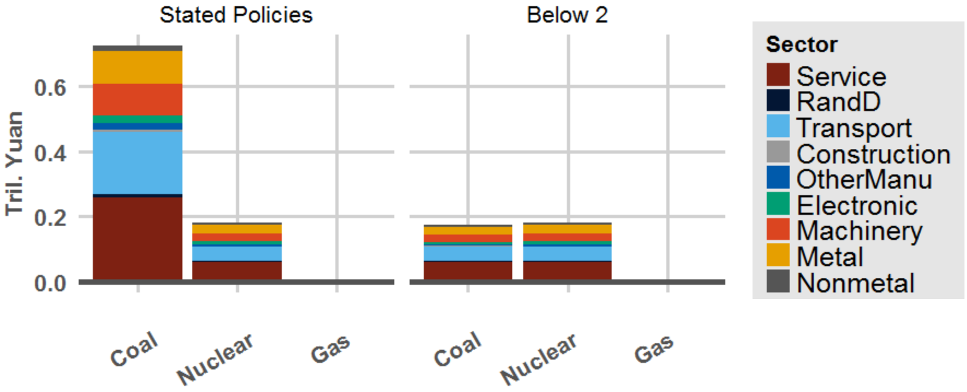


Figure 12-13 Stimulating effect of non-RE power on value added of other sectors in 2050



In the Stated Policies scenario, the power sector can be associated with 4.0% of the national GDP by 2050, including the direct contribution as well as the contribution from industries in the supply chain. Hereof, RE accounts for 3.4%-points, while fossil generation and nuclear account for 0.6%. In the Below 2 °C scenario, power generation plays a larger role in the total economy increasing to 5.1%, this should be seen in the light of the power sector taking on an increasing proportion of the final energy consumption, through electrification. Furthermore, the RE contribution increases to 4.7%-points, while the non-RE power generation drops to 0.4% of the overall GDP, including both the direct and indirect contributions to GDP.

12.4 Employment

The distribution of job creation among different sectors shows the similar pattern compared with that of outputs and value added. The employment is largely moved from conventional fossil fuel sector to machinery, services, and construction sectors, which indicates negative impacts of renewable energy development particularly on coal extraction, oil refinery sectors. This employment shift is a gradual process but would likely involve supporting measures from government and industry to smooth the transition.

In 2050 of Below 2°C scenario, renewable power sustains 14.2 million jobs in total, including direct jobs of 4.5 million jobs in the RE sectors, and 9.8 million jobs in other sectors. This is higher than the 11.7 million jobs sustained by RE power in the Stated Policies scenario by 2050. Hydropower, in the Stated Policies scenario, still takes the leading role of direct employment of RE sectors in the early years but its share over total RE employment will decrease. The employment share of wind and solar, however, will increase over time, and in both scenarios solar PV and wind sector will overtake hydro and become the largest employer in RE sector.

Figure 12-14 Direct employment of RE sectors from 2015-2050 in the two scenarios

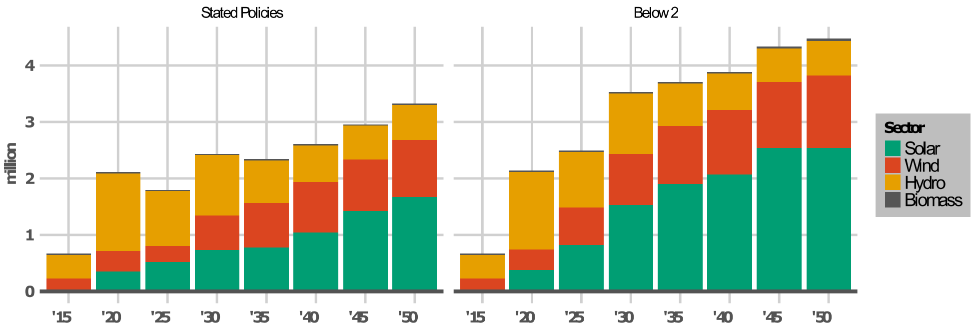


Figure 12-15 Indirect employment of RE sectors from 2015-2050 in the two scenarios

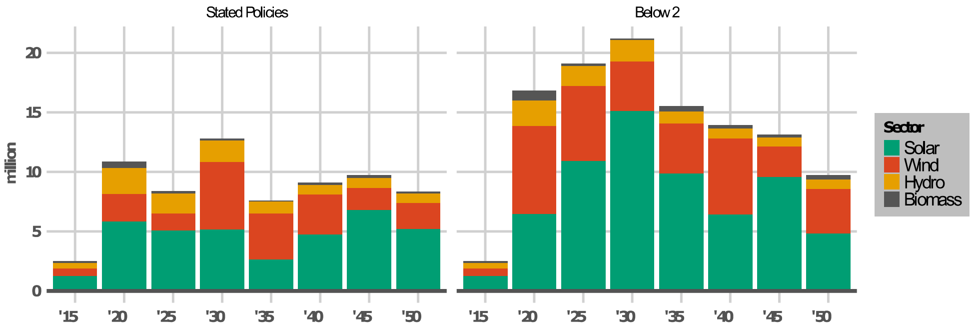
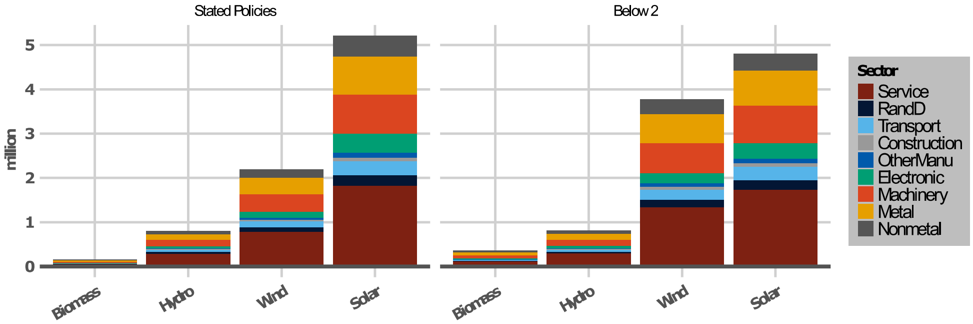
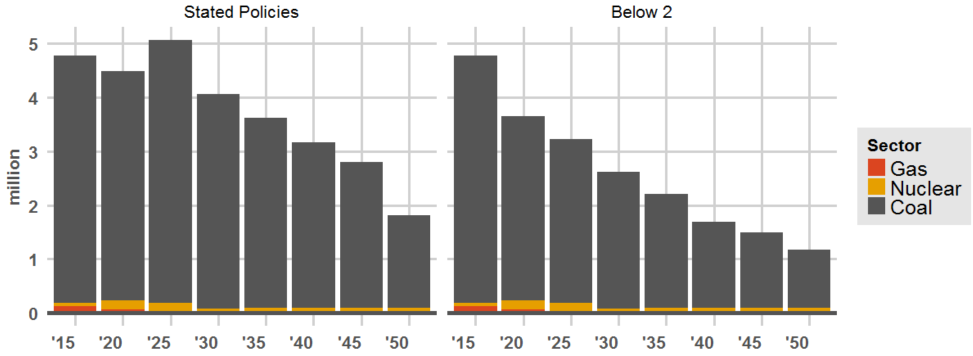


Figure 12-16 Breakdown of stimulated indirect employment effect from RE power sectors on subsectors in 2050



In the non-RE power generation, the jobs employment drops in both scenarios in fossil-fuel generation to 2.6 million in the Stated Policies scenario and 1.3 million in the Below 2 °C scenario, while the nuclear power industrial employment rises to 300,000 in both scenarios.

Figure 12-17 Direct employment in non-RE power sector



The indirectly induced employment is also affected. As Figure 12-18 and Figure 12-19 show, in 2050 of Stated Policies scenario, the total stimulated employment of coal power would be 870,000 and in the Below 2°C scenario 220,000, which is down from 5.82 million in 2015.

In total, the direct and indirect employment is 14.3 million in the Stated Policies scenario and 15.6 million in the Below 2 °C scenario, as totalled in Table 12-3. This indicates, that while demand for employment shifts between sectors, the power generation sector remains a key employment sector, also including the upstream industries supplying the sectors. The fact that the modelling shows a higher employment in the Below 2 °C scenario, indicates that new opportunities arise from the promotion of renewable energy, however, many careers will be affected as a consequence of the energy transition.

Figure 12-18 Stimulating effect on employment of non-RE power from 2010 to 2050

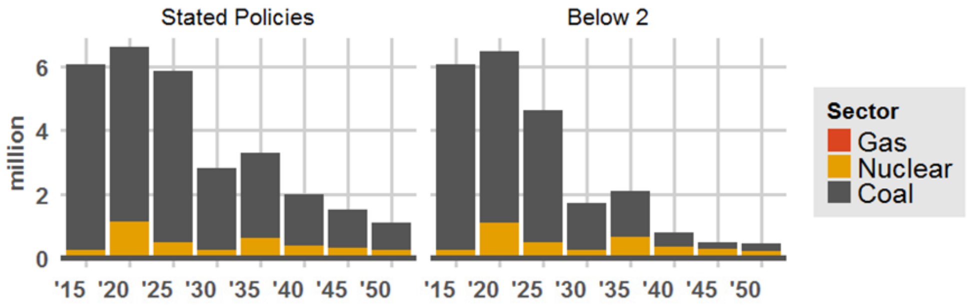


Figure 12-19 Indirect employment breakdown by industry as stimulated by non-RE power generation in 2050.

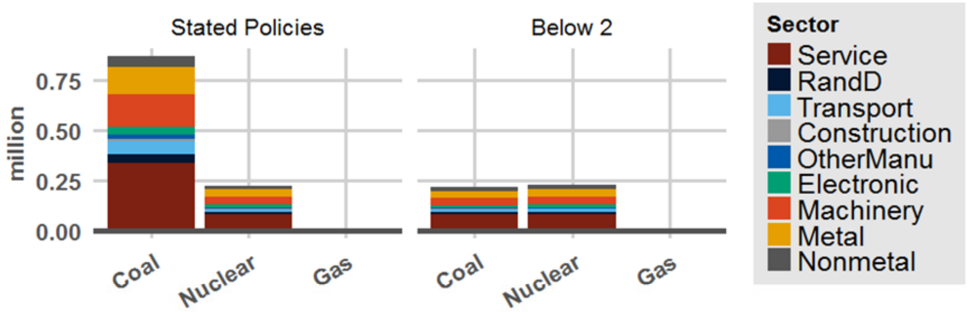


Table 12-3 Employment related to power generation by 2050 in the two scenarios

Million persons		Stated Policies	Below 2 °C
RE power	Direct	3.3	4.5
	Indirect	8.4	9.8
	Subtotal	**11.7**	**14.3**
Non-RE power	Direct	1.7	1.1
	Indirect	0.9	0.2
	Subtotal	**2.6**	**1.3**
Total power generation		**14.3**	**15.6**

The modelling can only to a limited degree identify structural barriers for these movements, while in practice shifts will instigate the need for accompanying reforms in the labour market, educational systems etc. As the most profound economic activity, which is set to decline in the scenarios is coal consumption, it is unsurprising that the most affected sector is coal mining, where employment is reduced to 20% of the 2015 level in the Stated Policies scenario and to 6% of the 2015 level in the Below 2°C scenarios by 2050. This presents a challenge for the transition of the energy industry, which will more likely need to be addressed with strong policy measures and a farsighted planning approach.

12.5 Summary of macroeconomic impacts

The approach to macroeconomic impact analyses employed in this study, provides insights into the structural shifts in the economy, which occurs when following alternative scenario pathways for energy transition. Because of the scenario design, the total GDP in alternative pathways will be essentially the same in total. Driven by the exogenous push and pull of the scenario setup, the stimulating effect of e.g. RE development, will be offset by the relative decline in other industries, as investment is redirected so follows output and value added.

The insights gained from the analyses are therefore useful to identify key areas where policy makers and planners must have emphasis, as summarised below:

- The development of renewable energy such a large scale as envisioned in the scenarios has wide-ranging implications, with socio-economic consequences.
- The RE-sector and specifically the RE power sector, stands to increase in relevance in the overall economy, contributing just short of 3.4% and 4.7% of total GDP by 2050 in Stated Policies and the Below 2°C scenarios respectively. This includes both direct and indirect value added. The non-RE power sector will decrease its contribution to GDP, and is less than 1/10 the size of the RE power sector in 2020 in the Below 2 °C scenario.
- Significant declines are indicated in energy intensive sectors such as construction, cement, iron and steel, mineral mining, and machinery. When investment is largely absorbed by renewable sectors and less goes toward the construction of fossil-fired power plants and other sectors, the demand for the products of the aforesaid high-carbon sectors goes down.
- Meanwhile, benefits can be gained by the upstream sectors of RE investment, e.g. electronic machinery, research and development sectors.

Within a 35-year timeframe, the scenarios indicate a significant shift will have to occur, in terms of the creation of alternative employment opportunities for large segment of the workforce. The positive message is that the growth in the RE energy deployment, will be in strong need for growth in employment, and therefore the policy challenges is to ensure supporting measures, to ensure that the workforce in the future is equipped with the right skills for the transitioned energy system, and that workers leaving declining industries are retrained to take part in the RE industrial development as well as find other opportunities.

13 Renewable energy outlook

Renewable energy will become central in the Chinese energy system. The following chapters analyse the resource potential, capacity, and production development of major renewable energy groups; wind power, solar energy, bioenergy, and hydropower in the two scenarios.

13.1 Wind power outlook

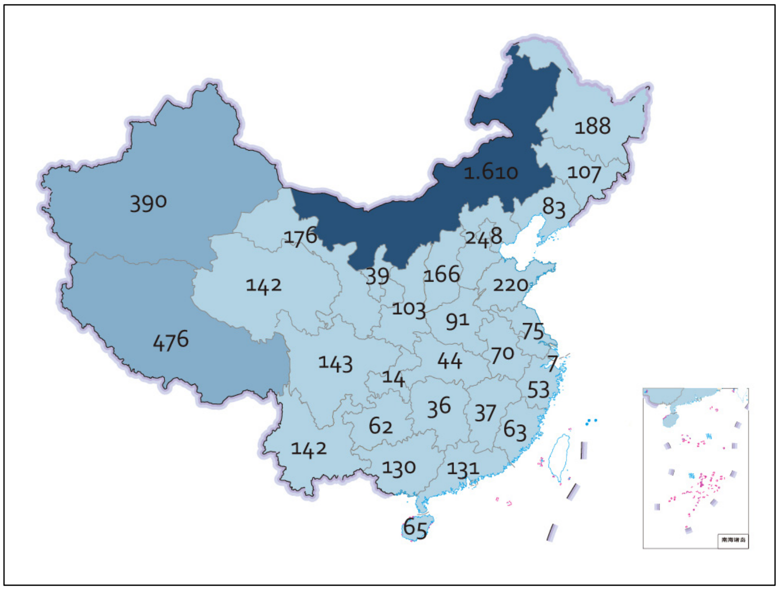
Current wind power development

By the end of 2016, China's cumulative installed grid-connected wind power capacity reached 148.6 GW, of which 1.5 GW was offshore wind power. China has become the world's largest and fastest growing market for wind power. Statistics from the Global Wind Energy Council show that the compound annual growth rate (CAGA) for global cumulative installed wind capacity was 22% during 2011-2016. During the same period CAGA in China reached 50%. In 2016, China installed 19.3 GW additional wind capacity, accounting for 43% of global additional capacity, making China a global leader in newly installed wind capacity. In 2016, China's wind power production reached 241 TWh, accounting for 4% of national power production. The immense growth in wind power has exposed some issues in the Chinese power system, i.e. software and hardware issues, incompatibility of power load and supply, inadequate grid flexibility, and lack of local and cross-regional power consumption balance mechanisms, among others. These issues make wind curtailment a significant challenge yet to be effectively addressed. For now, new projects have been suspended in regions with serious wind curtailment. However, newly installed capacity has been on the rise in the low wind speed middle and eastern regions, which are close to power load centers.

Resource potential

According to the latest national wind resource evaluation results, China's technical exploitation amounts of wind resources with a 70m height onshore wind power density of over 150 and 200 w/m2 are 7.2 TW and 5.0 TW, respectively; technical exploitation amounts of wind resources with an 80m height onshore wind power density of over 150 and over 200 w/m2 are 10.2 TW and 7.5 TW, respectively. Taking factors such as resource potential in low wind speed regions and land resource constraints into account, China's total wind energy potential is estimated to 4,899 GW onshore and 217 GW offshore.

Figure 13-1 China's resource potential of wind power (GW)



Cost assumptions

Wind power cost assumptions are divided by region and by type of turbine; standard onshore turbines, low wind speed onshore turbines, and offshore turbines. The present slow growth in offshore wind power development is taken into account and with it, its lower-than-expected cost reduction rates. It is assumed that average investment cost for onshore standard wind turbines will decrease by 12.8% to 6.8 yuan/w by 2030 compared to 2015 levels. This while investment costs for low wind speed turbines fall 15% to 8.02 yuan/w and offshore wind power investments costs is assumed to decline by 26% to 11 yuan/w. As shown in Figure 13-3 the operation and maintenance costs for all wind turbines are assumed to be reduced over time. For standard turbines costs go down to 59.3 yuan/w by 2030, down 8% from 2015 levels, for low wind speed turbines costs are reduced to 70 yuan/w by 2030, down 10% compared to 2015 and for offshore wind power operation and management costs are expected to fall to 94.8 yuan/w by 2030, down 8% compared to 2015. From 2030 to 2050 operation and management costs are assumed to decline slightly.

Figure 13-2 Assumed wind power investment cost development.

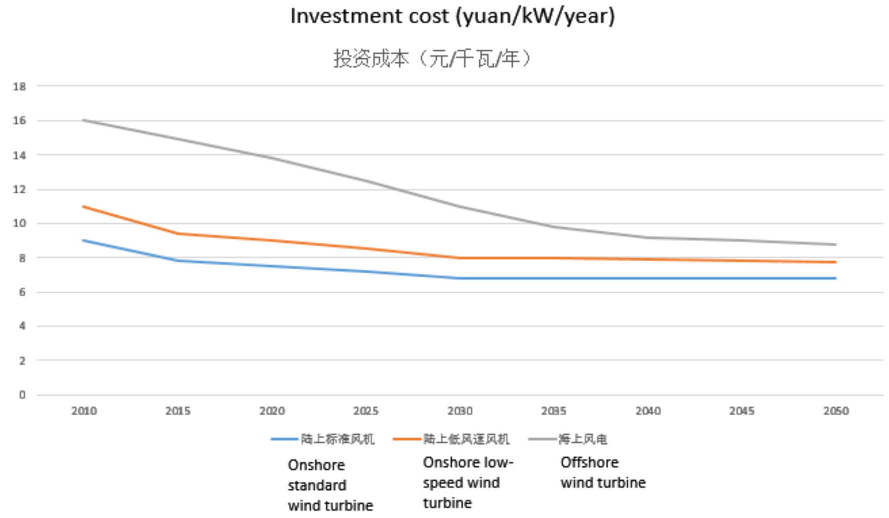
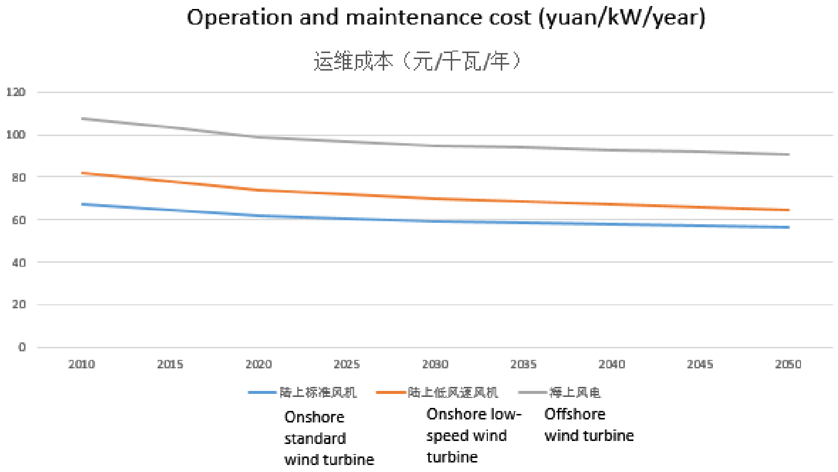


Figure 13-3 Assumed operational and maintenance cost development for wind power.



Model optimization

To better simulate wind power production, the EDO model has been updated to smoothen power curves. A power curve, which describes the relationship between wind turbine and wind speed, estimates the amount of electricity generated by wind turbine at a given wind speed. Different wind turbines have different power curves depending on differences in generator, impeller diameter and tower height. The model optimizes and smoothens power curves in accordance with each region's wind resource grade and time period. A region's power production is simulated based on factors such as the location of wind farm sites and chosen wind turbines. Output power curves are simulated at different wind speeds. For a low wind speed turbine, its assumed power production is 30% more than that of a standard wind turbine under low wind speed conditions.

Figure 13-4 Smoothened power curve simulated under the EDO model

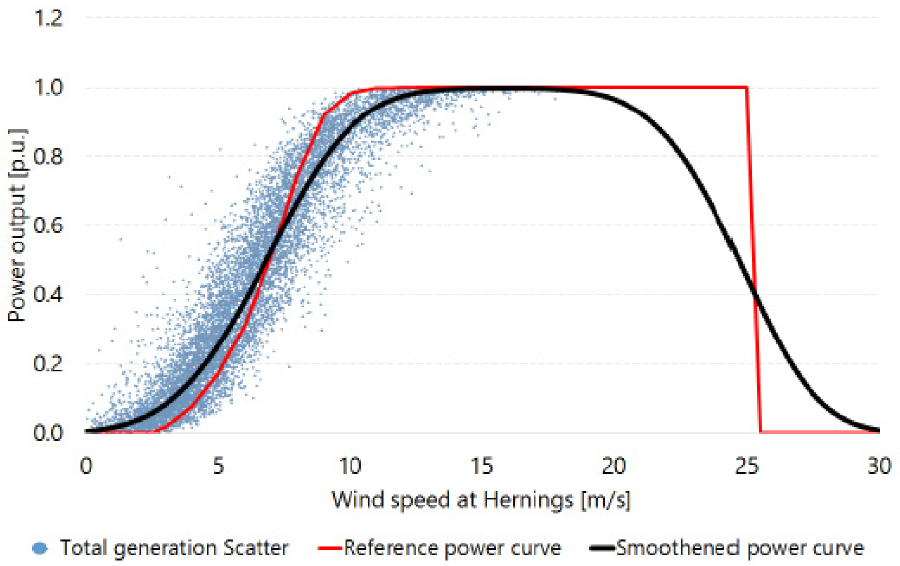
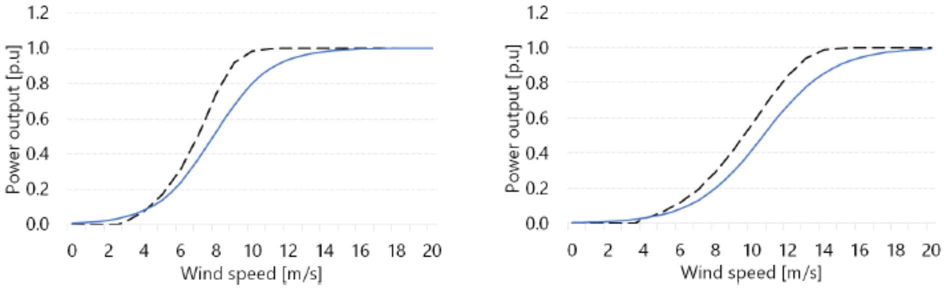


Figure 13-5 Result of power curve smoothing at different wind speeds (blue solid line denotes result of smoothing)



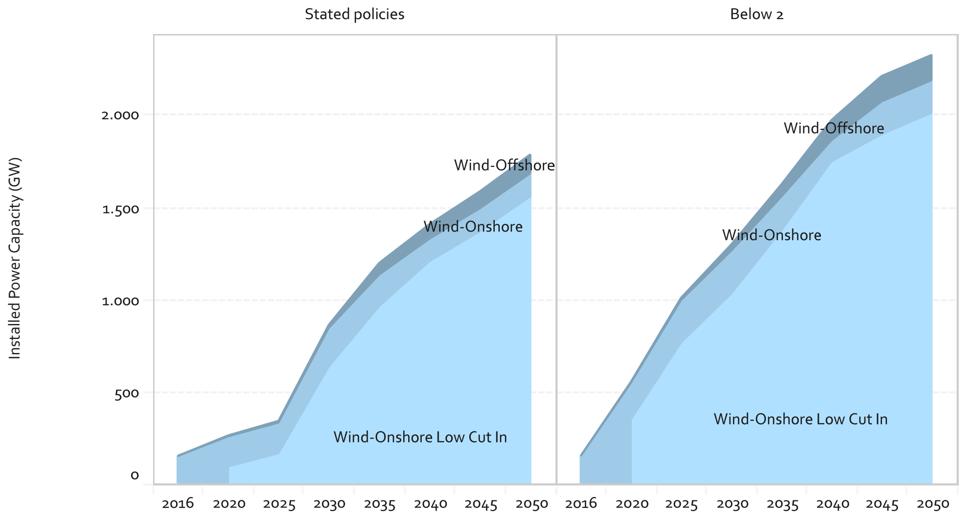
(a) 200 $W/m2$ (b) 400 W/mr

Installed capacity and power production

Figure 13-6 and 13-7 illustrate the installed capacity and production of wind power in the two scenarios. In the Stated Policy scenario installed wind power capacity is expected to reach 254 GW onshore (off which 90 GW low wind speed turbines) and 5 GW offshore by 2020. This will increase to 842 GW onshore capacity (including 632 GW low wind speed turbines) and 16 GW offshore wind turbines by 2030. Compared to CREO2016, there is more wind capacity development in the central and eastern low wind speed regions. The expansion in the central and eastern regions is due the proximity to load centers and curtailment issues in the three northern regions, while offshore deployment remains basically unchanged.

Supporting infrastructure, regulation, and a well-functioning power market will enable China to successfully develop its wind power industry in the Below 2 °C scenario. Main efforts will be directed towards onshore wind farms and to a lesser extent offshore wind turbines. Under the premise that grid connection and curtailment issues in the three northern regions are successfully solved, by 2020, installed wind power capacity will reach 544 GW are onshore wind (including 345 GW low wind speed turbines) and 5 GW offshore wind turbines. During 2020-2030, wind power will experience rapid growth, thanks to comprehensive power transmission capacity development and increased power system flexibility, in combination with technological breakthroughs, cost declines and successful power system reform. By 2030, onshore wind power capacity is expected to reach 1.257 GW (off which 1.026 GW low wind speed turbines) and 34 GW offshore. Wind power becomes crucial in meeting China’s power demand, improving the energy mix and bolstering the economic and social development. Production from onshore low speed wind power is the most prominent, whilst offshore wind power plays an increasingly important role in realizing the high-share renewable energy development goals.

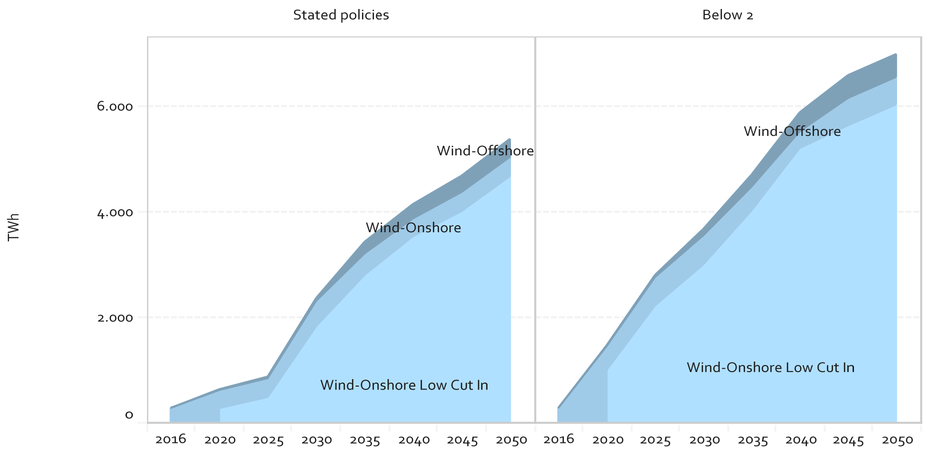
Figure 13-6 Comparison of development status of installed wind power capacity under different scenarios (GW)



	2016	2020	2030	2040	2050	2016	2020	2030	2040	2050
Grand Total	**149**	**259**	**858**	**1.403**	**1.782**	**149**	**549**	**1.292**	**1.966**	**2.320**
Wind-Offshore	1	5	16	78	103	1	5	34	109	137
Wind-Onshore	147	162	210	121	125	147	198	233	114	177
Wind-Onshore Low Cut In		92	632	1.203	1.554		345	1.026	1.743	2.006

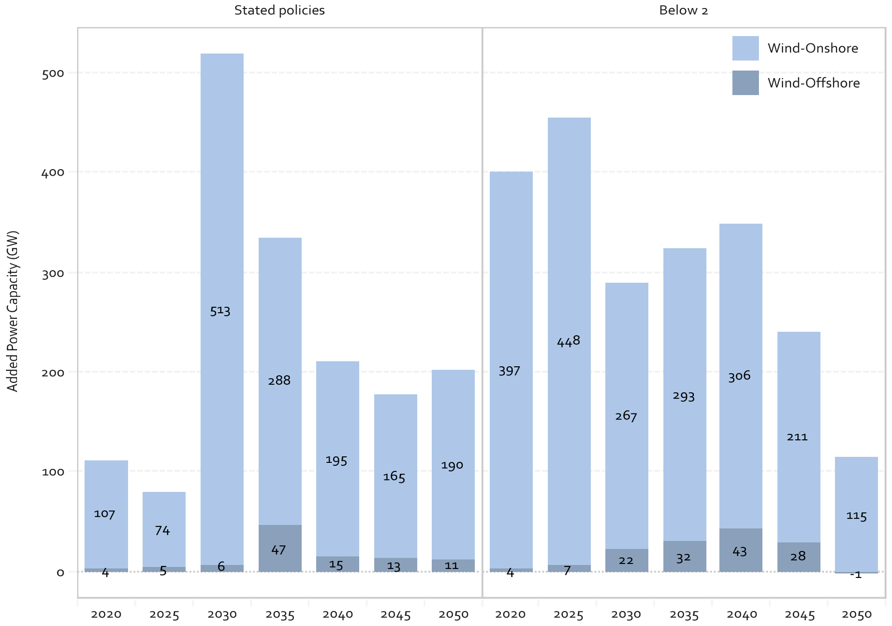
In the Stated Policy scenario, by 2020 and 2030, annual wind power production is expected to reach 619 TWh (including 15 TWh from offshore wind turbines) and 2,344 TWh (including 54 TWh from offshore wind turbines) respectively. In the Below 2 °C scenario, by 2020 and 2030, annual wind power production is expected to reach 1,451 TWh (including 15 TWh from offshore wind turbines) and 3,650 TWh (including 121 TWh from offshore wind turbines) respectively.

Figure 13-7 Development status of wind power production under different scenarios (TWh)



	2016	2020	2030	2040	2050	2016	2020	2030	2040	2050
Grand Total	265	619	2.344	4.123	5.358	265	1.451	3.650	5.857	6.963
Wind-Offshore	0	15	54	271	342	1	15	121	358	433
Wind-Onshore	265	343	480	337	363	264	452	551	315	521
Wind-Onshore Low Cut In		261	1.809	3.515	4.653		984	2.978	5.184	6.009

Figure 13-8 Additional capacity in the two scenarios (GW)



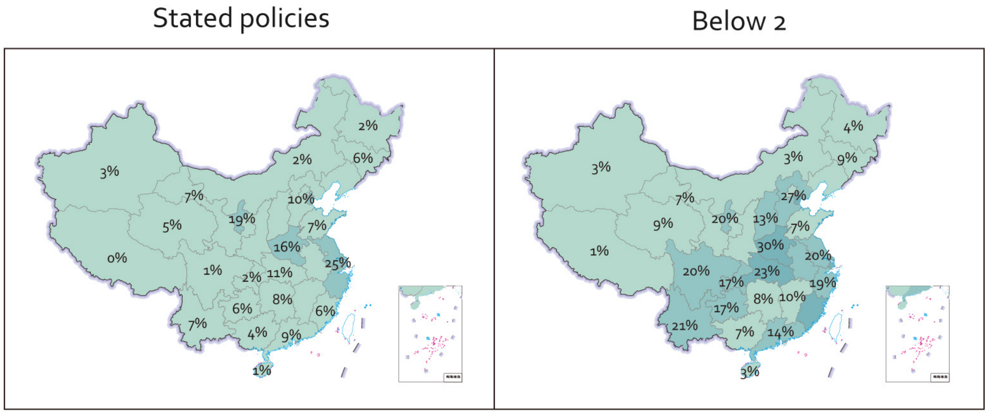
Short-term development

According to the 13th FYP for wind power development, by the end of 2020, cumulative grid-connected and installed wind power capacity must reach at least 210 GW, of which 5 GW or more is offshore wind power capacity. Annual wind power production must reach 420 billion kWh, accounting for approximately 6% of total national power production. Recent adjusted values, resulted from combining each province's development targets and distribution optimization, suggest cumulative grid-connected and installed capacity for 2020 to be 259 GW, of which 5 GW from offshore.

During the 13th FYP period, China's wind power distribution will be continuously optimized, accelerating development of onshore wind energy resources in the central, eastern, and southern regions. In the Stated Policies scenario added grid-connected and installed onshore wind power capacity in the central, eastern, and southern regions China will reach 42 GW, and cumulative grid-connected and installed capacity reach at least 70 GW by 2020. Provinces with serious wind curtailment issues will focus on solving these issued during the 13th FYP period. For areas where wind power takes up a relatively small share of their total electricity production, but without curtailment issues, the priority is to expand wind power development and local wind power consumption. After successfully solving the wind curtailment issue in the three northern regions by 2020, 35 GW of grid-connected and installed wind power capacity will be added by promoting local consumption and taking advantage of the existing transmission lines. This will make the cumulative grid-connected capacity amount to approximately 135 GW. During the 13th FYP period cross-provincial and cross-regional wind power consumption will be advanced, equal to 40 GW of transmission capacity (including pre-existing projects) in the three northern regions. In the Stated Policy scenario, the projected wind power development to 2020 is in line with the revised targets for the 13th FYP period, which are substantially higher than the minimum targets stated in the 13th FYP. This means that the 210 GW target generating 420 TWh is overachieved in the Stated Policies scenario. By 2020 259 GW wind power capacity is installed generating 619 TWh, 9% of national power generation. Achieving the policy targets for 2020 includes effectively utilizing wind power resources in the central and eastern parts of China, here low speed wind farm development will become central.

In the short term, certain changes will take place regarding onshore wind power resource deployment. Previous deployment focused on large-scale wind power farms in the three northern regions. This will change into a development model focused on low speed wind farms in the central and eastern parts of China. The economically developed eastern coastal regions will see the highest resource utilization rate, in the range of 16-25% by 2020 in the Stated Policies scenario. In the Below 2 °C scenario, apart from the above-mentioned regions, wind power resources in all other Chinese provinces and regions will also be developed and utilized. In the Below 2 °C scenario there is a higher degree of development in low wind speed areas. Here wind resources in the central and eastern parts of China, especially Henan, Hubei and Hunan provinces, are utilized at a large scale as shown in Figure 13-9.

Figure 13-9 Utilization of wind energy resources in 2020 under different scenarios



Mid-term development

In the Stated Policy scenario, by 2030, wind power capacity will be mainly distributed in Hebei, Inner Mongolia, Sichuan, Shandong, and Yunnan. In the Below 2 °C scenario, by 2030, cumulative installed wind power capacity in Inner Mongolia is expected to reach 181 GW, making it the largest among all wind power bases. The central and eastern parts of China will experience a rapid increase in the proportion of installed wind power capacity. In the mid-term 70 GW will be added annually in the central and eastern regions and by 2030 34 GW offshore wind capacity will be installed in the eastern region. Figure 13-10 shows the geographic distribution of installed wind power capacity in 2030 and

Figure 13-11 the regional development of added capacity. Previous extensive deployment in the northwest region is being reduced and the regional distribution of new capacity is getting more even. This is true in both scenarios, but it happens sooner in the Below 2 °C scenario. The development of wind power in the southwest will make use of the plentiful hydropower to balance power production. By 2030, wind resource development in the central and eastern parts of China is intensified. In the Below 2 °C scenario, development intensity in some regions may reach 70% or above.

To realize the target of limiting global temperature rise to 2 °C, the EDO model makes large-scale deployment and devises optimized distribution for wind power, deeming it the best cost-effective alternative energy source. Nevertheless, the Below 2 °C scenario, which is based on carbon emissions target, entails many uncertainties. Realization of the target is closely correlated with a combination of factors, i.e. China's power market construction, grid connection and consumption of wind power, progress in grid development, and development of supporting facilities for the wind power manufacturing industry, among others. In fact, wind power distribution and total quantity estimation under the Below 2 °C scenario creates even more prominent challenges for wind power development.

Figure 13-10 Wind power development situation in 2030 under different scenarios (GW)

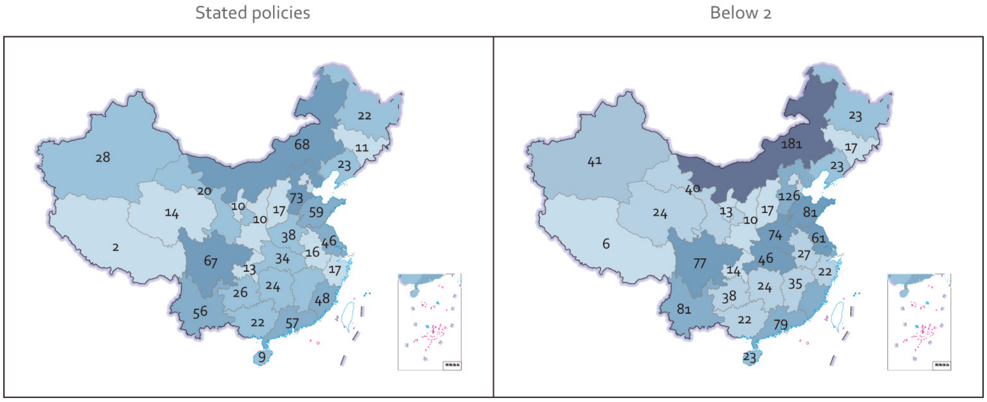


Figure 13-11 New installed wind capacity by region in the two Stated Policies scenario (SP) and the Below 2 (B2) scenario.

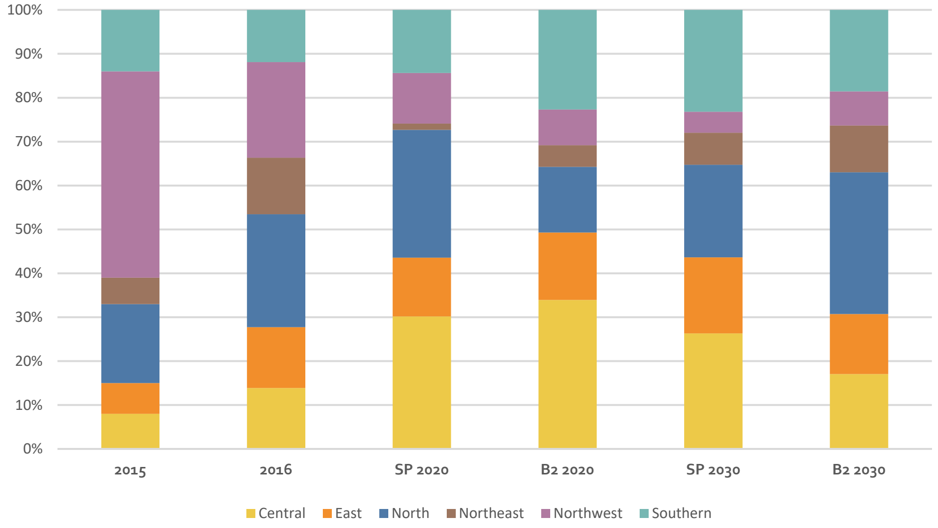
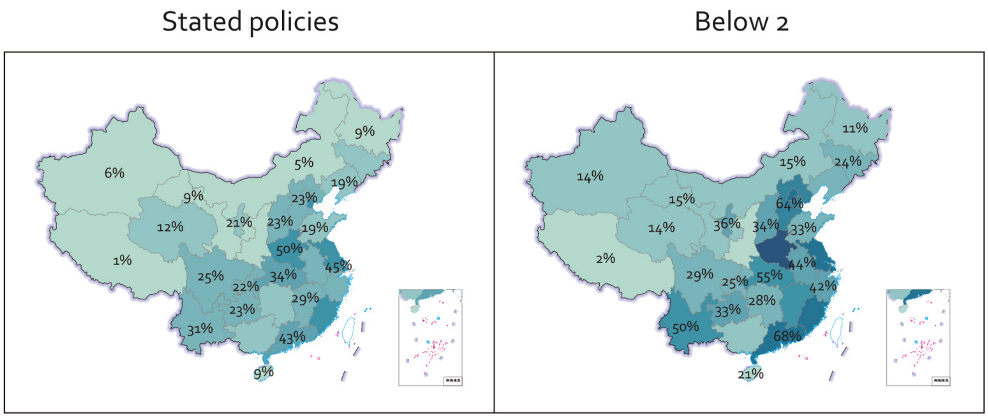


Figure 13-12 Wind energy resource development situation in 2030



Long-term development

By 2050 wind power production will be able to meet 42.7% of total electricity production and total installed wind power capacity accounting for 38% of total installed generation capacity in the Stated Policies scenario. Under the premise that no wind curtailment takes place and the construction of power grid supporting facilities is fully on schedule, wind power development will be mainly concentrated in Inner Mongolia, Hebei, Sichuan, Yunnan and economically developed eastern coastal provinces. In the Below 2 °C scenario, by 2040, installed wind power capacity will account for 41% of total installed power generation capacity. Wind power production will be able to cover 46% of total electricity production. By 2050, installed wind power capacity is expected account for 39% of total installed generation capacity and wind power production will still cover 46% of total electricity production. In this scenario, wind energy resources in the central and eastern parts of China are fully utilized. This while wind energy resources in other middle- to low- wind speed regions, plateau and high attitude areas, are also utilized at a large scale. In this scenario, wind power is the power source with the largest installed capacity and it occupies the most significant position in the power system.

Figure 13-13 Wind power distribution for 2050 under different scenarios (GW)

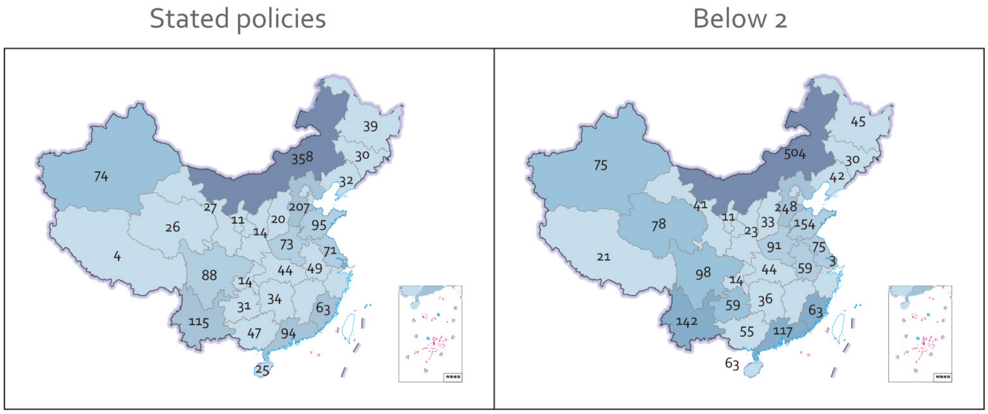


Figure 13-14 illustrates the situation of offshore wind power development in 2050. In the Stated Policy scenario, installed offshore wind power capacity is expected to reach 104 GW. In the Below 2 °C scenario, installed offshore wind power capacity will reach up to 137 GW. The offshore resource potential is assessed to 200 GW or so; in other words, in the Below 2 °C scenario, nearly 70% of offshore wind energy resources are utilized. Realizing the Below 2 °C scenario and development of relevant industries, i.e. offshore wind power technology, marine planning and construction capacity, are mutually bound to each other. To realize this scenario, China must intensify support for offshore wind power development, promote technological progress, cost reduction in offshore wind power and do a good job with pre-planning assessments.

Figure 13-14 Offshore wind power distribution for 2050 (GW) (left: Stated Policies; right: Below 2 °C)

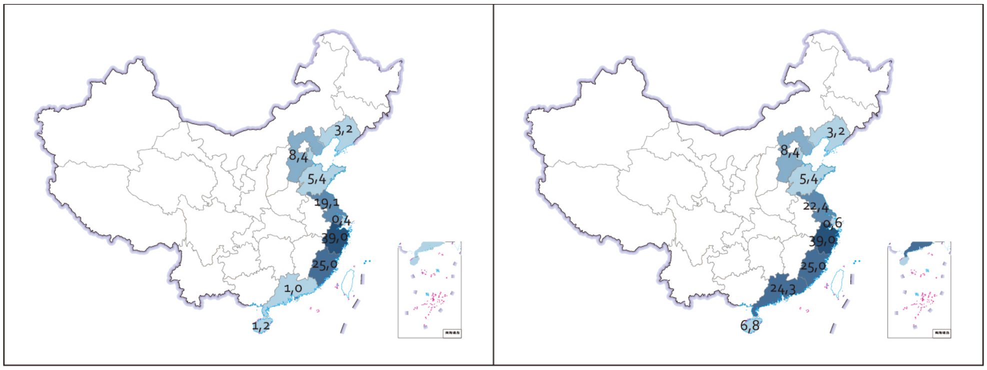
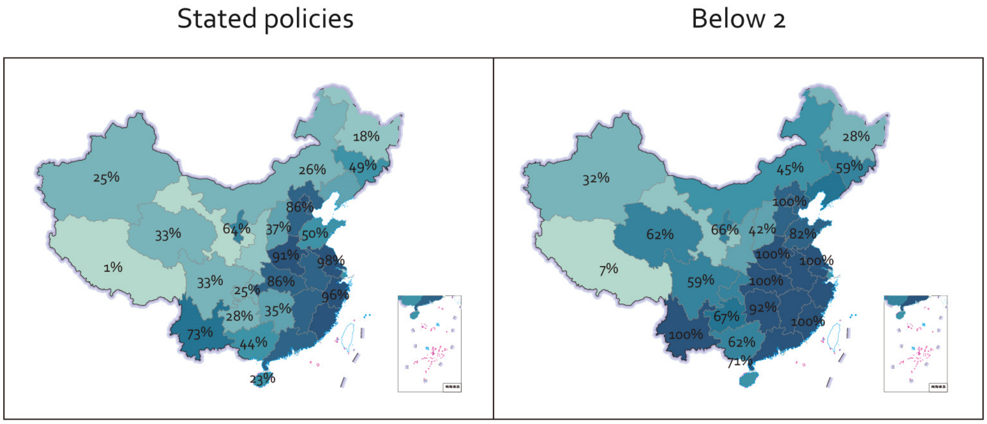


Figure 13-15 Wind energy resource development situation in 2050



13.2 Solar energy outlook

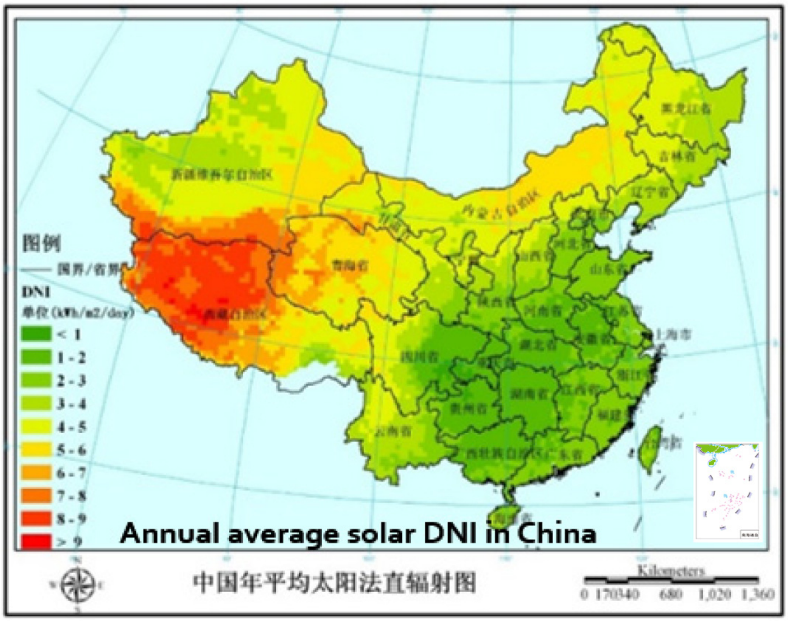
Solar power generation

Resource potential

Solar energy resources depend on solar radiation and suitable locations for installing solar capacity. The EDO model divides solar radiation resources, by the form of solar power generation resources, into direct and indirect solar radiation resources; based on the solar radiation resource status over time in different locations. The model simulates and analyses the output of different solar energy technologies; tracking solar PV power generation, concentrated solar power(CSP) generation, centralized, and distributed solar PV power generation, among others.

Judging from solar radiation, China’s total solar resources are abundant. Overall, there are more resources in the plateau than in the plain and more in the western arid region than in the eastern humid region. Of all regions, the Tibetan Plateau has the richest solar radiation resources, with its annual total radiation exceeding 1,800 kWh/m^2, or even 2,000 kWh/m^2 in certain areas, while solar radiation resources are at a relatively low in the Sichuan Basin. Solar DNI (direct normal irradiance) is a key factor affecting solar thermal and tracking solar PV power generation. As shown in Figure 13-16 China's solar DNI resources demonstrate a gradually decreasing trend from the west to the east.

Figure 13-16 Annual average solar DNI in China



As for suitable application areas, distributed PV is not only applicable for rooftops. Potential installation sites provided by new distributed solar PV application forms, e.g. greenhouses, abandoned mining sites, and fish farms, are tremendous. Hence, the EDO model gives consideration not only to land resources required for the installation of centralized solar PV and CSP generation, but also to rooftops for distributed solar PV systems and the space available from integrated agriculture-solar and aquaculture-solar systems as well as old mine sites.

Based on solar radiation and land resources in Chinese provinces, the construction status of future power transmission lines and the effects of industrial distribution on electric load, the EDO model analyses and calculates each province's development potential for centralized solar PV power generation. Meanwhile, it further analyses each province's development potential for distributed solar PV power generation in accordance with the building area distribution, installation space resources for new-type distributed solar PV power generation, electric load and development status of distributed solar PV power systems. Taking into account such factors as the DNI resources, water resources, and topographic conditions required to meet the basic conditions for CSP development, the EDO model analyses and calculates the development potential for CSP generation.

Figure 13-17 Utility scale (left) and distributed (right) solar PV development potential in Chinese provinces (GW)

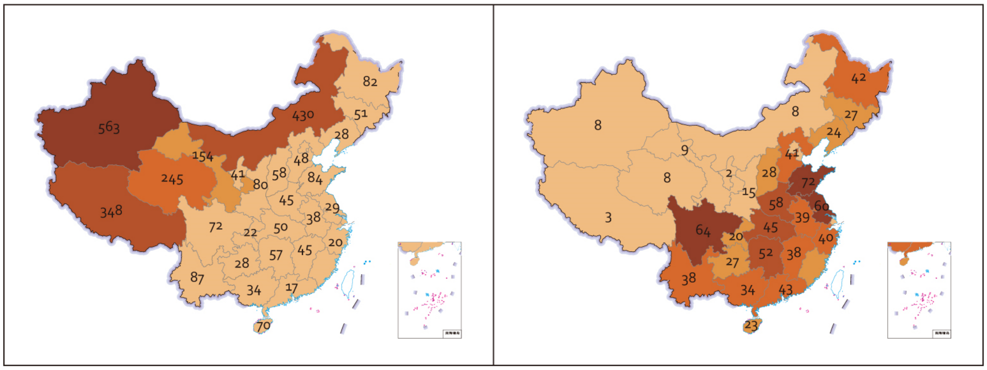


Table 13-1 China's solar power generation development potential

Application Form	Development Potential (GW)
Centralized solar PV power plants	2537
Distributed solar PV system for buildings	541
Other distributed solar PV systems	372
CSP plants	308
Total	3757

Technological development

Current development status

So far, solar PV power generation has been applied at a large scale in China. As of the end of 2016, China's cumulative installed solar PV capacity surpassed 77GW, at an annual growth of 34 GW. In terms of both cumulative and new installation, China has become the world leader. Solar PV power generation has turned into one of the crucial renewable power generation technologies in China, and is playing an increasingly important role in the country's energy transformation and development. With the rapidly-expanding scale of solar PV power generation applications, particularly large-scale deployment of centralized solar PV application in the northwest region, the phenomenon of solar curtailment has been worsening. This is due to incompatibility between power load and supply and lack of a balancing mechanism for cross-regional electricity consumption.

Distributed solar PV potential, shown in figure 13-17, is close to load centres with no need for long-distance transmission and distributed solar PV has witnessed rapid growth in recent years. It is especially the case with the central and east regions which have a relatively large power demand. Distributed solar PV power generation, albeit still taking up a small market share at about 13% of total installed solar PV capacity, holds massive future development potential.

Currently, CSP generation is still in a demonstration and scaling up stage before large-scale application. In 2015, China launched the first batch of 1.4GW CSP generation demonstration projects, the construction and operation status of which is expected to exert a major influence on CSP generation development in the future.

Technology development and cost assumptions

Solar PV power generation technology has already become one of the most important renewable power generation technologies. With more and more investment poured into research and development of solar PV power generation, all types of solar PV power generation technologies will experience rapid development in the future. Of these technologies, crystalline silicon photovoltaic cells will still remain the mainstream technology in the market in the near to medium term. Its development will be mainly dependent on continuously reducing cell manufacturing costs and enhancing the competitiveness of photovoltaic power generation from crystalline silicon by creating thinner silicon wafers, lowering the usage amount of silver paste, improving the conversion efficiency of solar cell and preparing silicon at a lower cost (e.g. fluidized bed method). Thin film technology will still be a key technology for future research and development. The development focus, however, will be on creating cell products with high conversion efficiency and low attenuation ratio, developing a full array of flexible photovoltaic application products and building integrated PV. The future market development focus of concentration photovoltaics will be on improving system reliability and reducing its power generation costs.

Currently, CSP generation technology is still in a demonstration and scaling up stage in China. With advances in technology and scale development in the future, it is expected to become one of the major renewable electricity sources capable of bolstering the base load. In the future, the focus of technological development will be evolving in a high-parameter and high-efficiency path. Meanwhile, development of large-volume heat storage technologies and application of combined operation technologies will enable CSP generation to undertake a part of the base load. In the application fields, cascaded energy utilization technology, e.g. combined power and water/power and heat, will help to improve the comprehensive energy utilization efficiency of CSP generation systems.

Technology cost for PV power generation is expected to decline (as shown in Table), taking the following factors into account:

- Module cost declines attributed to improved module conversion efficiency of various types of photovoltaic power generation technologies.

- Uses of low-cost materials.
- Reduction in material consumption.
- Reduction in levelized cost of electricity (LCOE) attributed to improved performance ratio of solar PV power generation systems.
- Extended lifetime of power generation modules.

Regarding CSP generation, advances in CSP generation technologies, reduction in CSP generation investment costs attributed to expansion of CSP applications, and development of relevant industries istaken into account when investment costs are assumed.

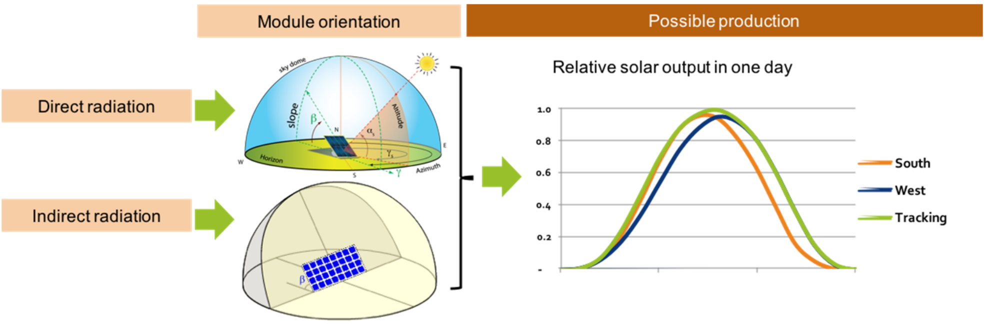
Table 13-2 Assumed investment costsfor future solar power generation technologies it the EDO model (mRMB/MW)

	2020	2030	2040	2050
Centralized solar PV power plant	4.8	4.2	3.5	3.0
Distributed solar PV power plant	5.0	4.4	3.7	3.2
CSP plant	25	13	12	11

Model optimization

Regarding solar energy development, the EDO model conducts an optimization calculation based on different forms of solar power generation applications, direct and indirect solar radiation resources in different regions, and electric loads in different regions. Regarding different installation methods for various types of solar PV power generation systems, e.g. tracking solar PV power generation, the EDO model employs a simulation optimization technique for output curves of solar PV power generation systems installed towards different directions and at different angles. With the varying solar angles throughout the day, solar PV application technologies such as a tracking solar PV system or one installed towards different directions or angles takes full advantage of indirect solar radiation. This significantly increases a solar PV system's output in the morning or at dusk when direct solar radiation is low, and hence smoothening the day-time output curve of the entire solar PV system.

Figure 13-18 Simulation optimization of solar PV power system output under the EDO model

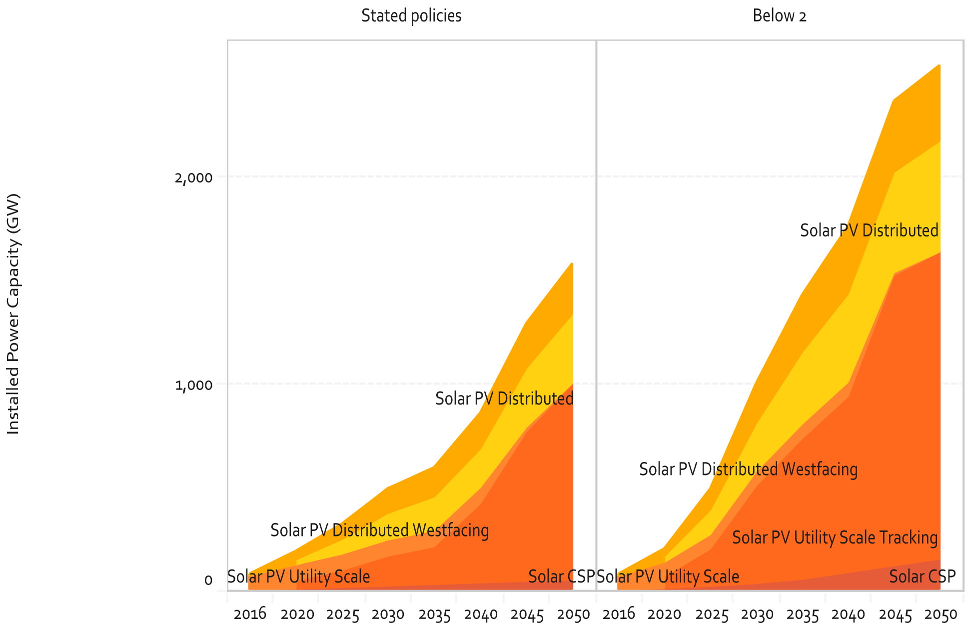


Development scale and distribution

The EDO model describes two scenarios for solar power generation until 2050: the Stated Policy scenario and the Below 2 °C scenario. The Stated Policy scenario illustrates development trends for solar power generation where current policy trends are maintained and well implemented, whilst the Below 2 °C scenario depicts development prospects of solar power generation and its role in the power supply structure where efforts are made to cope with global climate change and to limit global warming within2 °C.

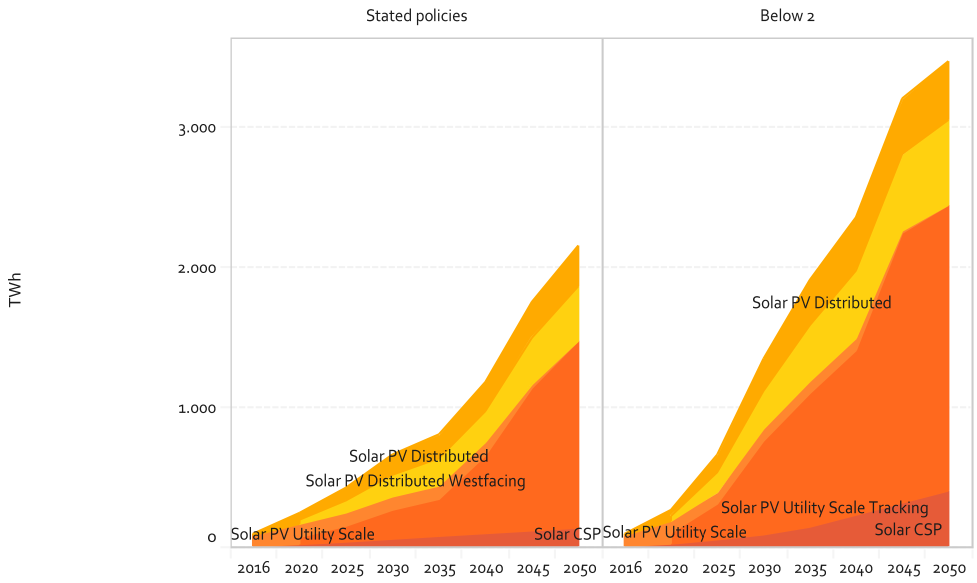
The EDO model simulates and analyses the solar PV power generation installation capacity and electricity output of each province based on the development trends of China’s energy structure and energy consumption revolution, the country’s non-fossil energy development targets, and each province's solar energy generation development potential, as well as technical and economic efficiency factors.

Figure 13-19 Installed solar power capacity under two development scenarios (GW)



	2016	2020	2030	2040	2050	2016	2020	2030	2040	2050
Grand Total	77	188	490	856	1,580	77	200	1,000	1,760	2,539
Solar PV Distributed	10	42	119	174	245	10	38	195	329	367
Solar PV Distributed Westfacing		24	129	187	335		28	232	425	536
Solar PV Utility Scale	67	77	78	78	1	67	69	70	70	1
Solar PV Utility Scale Tracking		40	144	381	950		59	472	851	1,485
Solar CSP	0	5	20	35	50	0	7	32	85	150

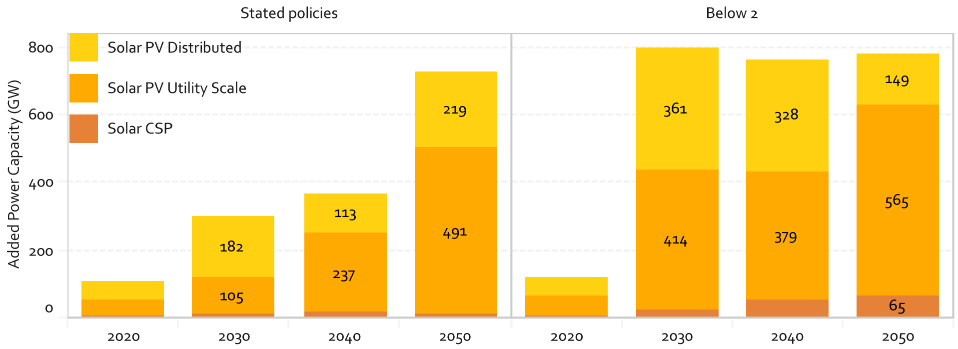
Figure 13-20 Electricity outputs from solar power generation under two development scenarios (TWh)



	2016	2020	2030	2040	2050	2016	2020	2030	2040	2050
Grand Total	**89**	**237**	**653**	**1.169**	**2.141**	**89**	**259**	**1.334**	**2.341**	**3.453**
Solar PV Distributed	11	49	145	207	290	11	44	229	380	418
Solar PV Distributed Westfacing		30	155	221	387		35	270	482	605
Solar PV Utility Scale	79	94	95	95	1	79	85	86	86	1
Solar PV Utility Scale Tracking		52	207	553	1.332		77	666	1.171	2.034
Solar CSP	0	14	52	93	131	0	18	84	224	396

Based on the technical characteristics of solar power generation applications in different forms, the EDO model employs a simulation optimization technique for output curves of solar PV power generation systems, with a particular emphasis on the energy storage characteristic of CSP generation, in an effort to fully explore the potential of solar power generation and discover optimal distribution of market sizes for solar power generation applications. Under these two scenarios, during 2020-2030, distributed solar PV, given its advantages in being close to power load with no need for long-distance transmission and possible cost reductions, is set to take a majority market share, with its growth rate significantly higher than that of utility scale solar PV power plants. In the long term, however, whilst technical and economic efficiency is taken into full account, centralized solar PV power plant will be able to occupy a majority market share by 2050, thanks to optimized national power supply structure and power load and improved transmission lines.

Figure 13-21 New installed solar power capacity under two development scenarios



Short-term outlook

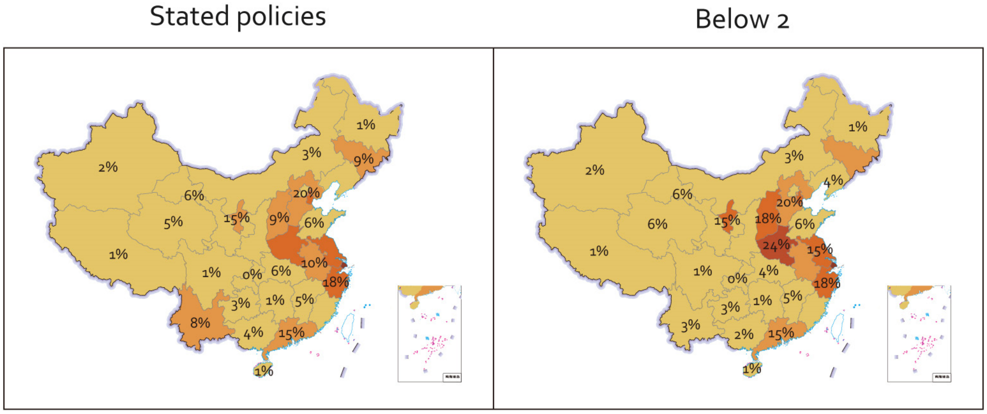
In the Stated Policy scenario, solar PV power generation market will develop rapidly in the short-term. Following the target set out in China's 13th FYP for Solar Energy Development, China is on its way to overachieve the solar PV power installation capacity target of 105 GW by 2020. This is only a guiding minimum development target, but based on present solar PV power generation market growth, this target will be reached as early as 2017. In light of China's present policy documents and framework, as well as the power grid construction status and in light of the fact that conventional power and solar PV systems are to possess certain regulating abilities which increases flexibility by 2020, curtailment of solar PV power will thus be basically solved. Declining solar PV generation costs will make grid parity a reality, at least on the user side. In the Stated Policies scenario solar PV is expected to reach 183 GW, including 183 GW of total installed solar PV capacity (which is made up of 117 GW of centralized and 22 GW of distributed solar PV capacity), and 5 GW of installed solar thermal capacity.

In the Stated Policy scenario, CSP generation will be mainly in a stage of large-scale power plant application, demonstration and scaling up during the 13th FYP period, when the manufacturing capability of the thermal power generation industry is cultivated. Following the present policy development, the targets set out in *the 13th FYP for Solar Energy Development* and progress in existing demonstration project construction, CSP generation is on track to achieve an installation capacity of 5 GW and electricity output of 14 TWh by 2020. Solar power in total will generate 223 TWh, making up 3.5% of the national power generation.

In the Below 2 °C scenario, the power grid construction process is accelerated in the short-term. Curtailment of electricity from solar PV power as well as power transmission, will not hinder the solar PV development. The cost of solar PV power generation is expected to reach full grid parity on the user side by 2020. By then, the solar PV market size will reach 194 GW(which is made up of 128 GW of centralized and 66 GW of distributed solar PV capacity).As CSP generation remains in a demonstration and scaling up stage, its development scale will reach 7 GW, and electricity output will amount to 18 TWh. Solar power in total will generate 259TWh, making up 3.8% of national power generation.

Based on the analysis and calculation results of each province's development resources for solar PV power generation, the EDO model simulates the solar PV installation capacity as a share of available resources in each province by 2020 under the two scenarios. Under both scenarios, development of the distributed solar PV market is accelerating, with a higher growth rate than that of the centralized solar PV market.

Figure 13-22 Solar PV power generation development in 2020 as a share of resources in the two scenarios.



Stated policies

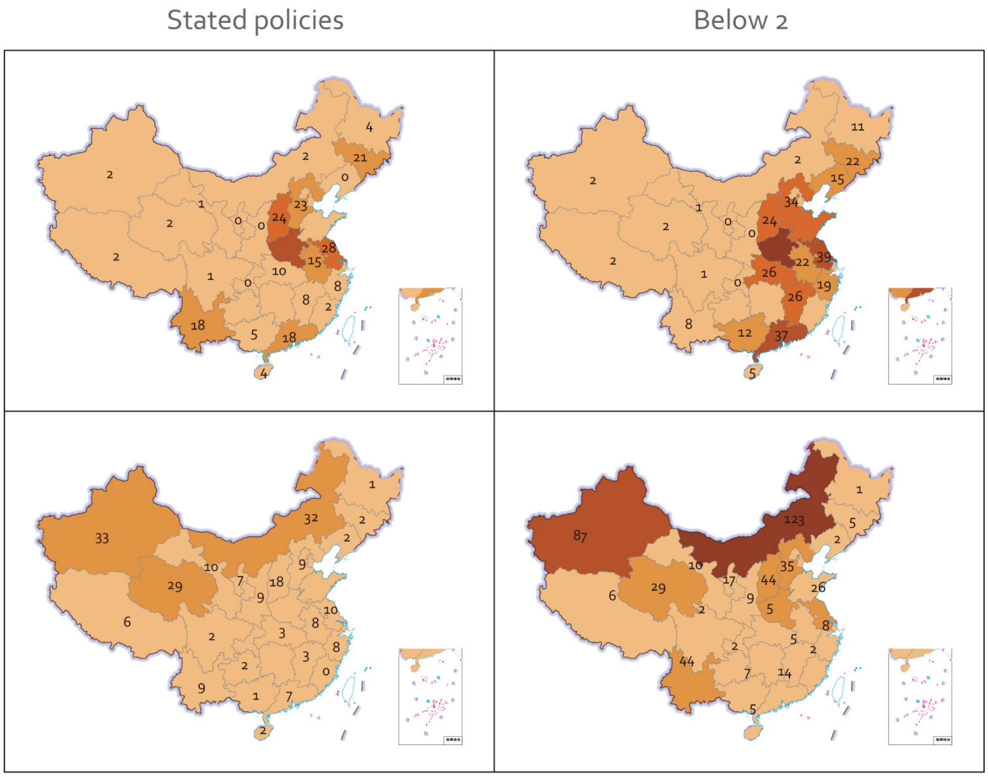
Below 2

Medium-term outlook

The period 2020-2030 will be a crucial period for China's energy sector development. In the stated policies scenario solar PV installation capacity is expected to reach 470 GW (which is made up of 222 GW of centralized and 248 GW of distributed solar PV capacity). With the increased integration capability of CSP generation, in particular scaling up the supply chain, CSP generation costs will decline rapidly. Combined with the power system reform and the advantage of thermal power generation in smoothing power supply, CSP will play an important role in the supply structure. Till then, CSP generation installation capacity will reach 20 GW, and its electricity output will be 52 TWh. Total electricity output from solar power will be 653TWh, making up 7% of national power generation.

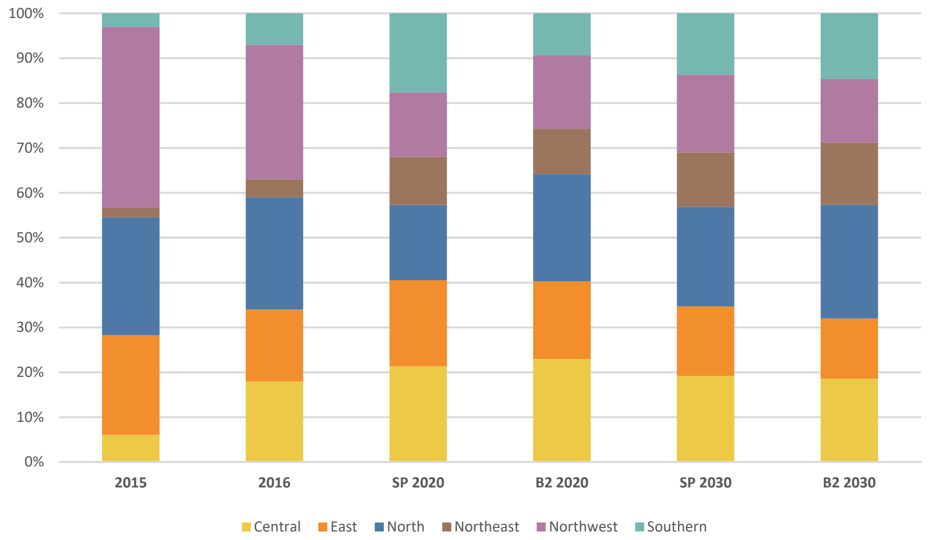
In the Below 2 °C scenario by 2030, the solar PV market size will reach 969 GW (made up of 542 GW of centralized and 427 GW of distributed solar PV capacity). CSP generation as one of the major renewable electricity sources capable of bolstering the base load will witness scaling up to a large scale, with its installation capacity to amount to 32 GW and electricity output to 84 TWh. Total electricity generated from solar power plants will reach 1,334TWh, making up 13.4% of power generation.

Figure 13-23 Distributed (top) and utility scale (bottom) solar PV installation capacity of by province in the Stated Polices scenario (left) and Below 2 °C scenario (right) in 2030.



Distributed solar PV power generation will witness extensive development by 2030, with declining costs and increased market competitiveness. In the central, eastern, and southern regions, large-scale development and utilization of distributed rooftop solar PV systems will appear in industrial parks, economic development zones, and large public facilities. Large-scale utilization of distributed solar PV applications in places like water surfaces, greenhouses, highways and railways will also take place. Affected by solar PV power transmission and power load factors, however, market growth in the northwestern region will be slowing down. In China's middle-eastern and northeastern regions, utility scale solar PV power plants will develop fast, which will demonstrate how to reconstruct abandoned coal mining sites and deploying advanced PV technology. In terms of market distribution, the focus of solar PV power generation will shift from the northern and central regions to the middle, eastern, and southern regions.

Figure 13-24 Market distribution of solar PV power generation in 2015, 2016 and for the Stated Policies scenario (SP) and Below 2 °C scenario (B2) for 2020 and 2030.

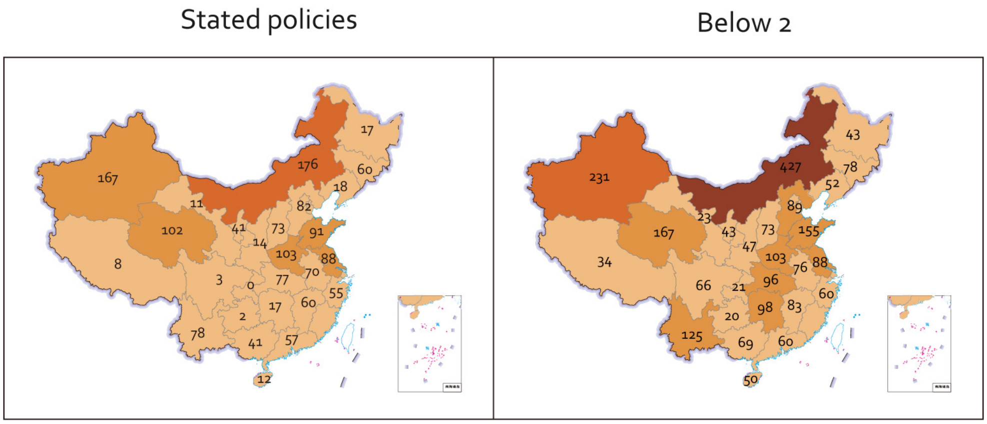


Long-term outlook

In the Stated Policy scenario, after 2030, high-proportion and high-penetration solar PV system and power grid system technologies, as well as power transmission, will be all able to support solar PV power generation. Solar PV cell efficiency will be improved significantly; sites to install solar PV, e.g. agricultural greenhouse, water surface and roadway, are utilized at a large scale; and energy storage, smart grid and solar PV integration technologies are scaled-up to large scale. Installed solar PV capacity will reach 821 GW, and electricity output will reach 1,076 TWh by 2040.By 2050, installed solar PV capacity will exceed 1,530 GW(made up of 950 GW centralized and 580 GW distributed solar PV capacity). After 2030, resulting from further cost reductions and notable competitiveness in the fields of efficiency, operating hours and cost per unit of electricity, market growth in CSP generation will be accelerating. CSP will take up a certain market share in the power source structure supporting the base load. By 2040, installed CSP capacity is expected to reach 35 GW, and electricity output will be 93 TWh. By 2050, installed CSP capacity will reach 50 GW, and electricity output will reach 131 TWh. In 2050 total solar power output will reach 2,141TWh and make up 17% of power generation.

In the Below 2 °C scenario, in order to significantly reduce GHG emissions, vigorous efforts will be made to push forward the development of solar power generation. In the long-term, all restraining factors affecting the transmission and consumption of solar power will be eliminated and the policy framework will be further improved. By 2040, installed solar PV capacity will exceed 1,675 GW, and electricity output will reach 2,117 TWh. By 2050, installed solar PV capacity will reach 2,389 GW (made up of 1,486 GW centralized and 903 GW distributed solar PV capacity). When utilized to its full potential, CSP power generation has the technical advantage of smoothing power output. Hence, it will take up a relatively big market share in the power source structure that supports the base load. In the meantime, with rapid cost declines, thermal power generation will be able to compete with conventional energy sources. By 2040, installed CSP capacity is expected to reach 85 GW and electricity output will reach 224 TWh. By 2050, installed CSP capacity is expected to reach 150 GW and electricity output will reach 396 TWh. Total solar power output will reach 3,453TWh and make up 23% of power generation in 2050.

Figure 13-25 Installed solar power capacity in 2050 under the two development scenarios



Solar thermal utilization

Resources and potential

In China, most regions have abundant solar radiation resources. The application potential for solar thermal utilization is mainly affected by thermal demand and available installation space. Comprehensive analysis of a combination of factors, i.e. thermal demands of different Chinese climate regions, development trends for building areas, green building energy consumption development trends, industrial energy consumption, and energy conservation, reveals that, installation potential for solar thermal utilization in buildings will reach 8500 GW_{th}[52] (12.1 billion m^2 in collector area) by 2020. This is based on the assumption that the building area suitable for solar thermal utilization is 40% of total usable building areas. As building areas remain basically the same in 2030 and 2050, installation potential for solar thermal utilization are 9,100 GW_{th} (13.0 billion ^{m2} in collector area) in both 2030 and 2050.

Technology development

Solar thermal utilization in China is commercially viable. Being a mature and widely applied technology, it is mainly used for domestic hot water supply. As of the end of 2016, China's

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[52] Installed capacity for each square meter of collector area is 700 W_{th}.

cumulative installed solar thermal utilization capacity reached 324.5 GW_{th} (464 million m^2 in collector area), accounting for approximately 71% of global cumulative installed capacity and making China a world leader in solar thermal utilization and installed capacity.

In the future, solar thermal utilization and application will gradually shift from domestic hot water supply to solar heating, cooling and industrial/agricultural heat supply. Regarding solar heating and cooling, priority will be on developing advanced heat storage technology, improving system integration capability, and developing all-year-round integrated solar energy utilization systems, e.g. combined solar hot water, space heating and cooling systems. In agricultural and industrial solar energy application fields focus will be on:

- Conducting research and development of high-performance solar collectors and reliable high-performance systems.
- Improving the output temperature and photothermic conversion efficiency of solar collectors.
- Enhancing the design capability for solar collecting system and conventional energy system. Integration.
- Improving the contribution of solar thermal utilization in meeting industrial and agricultural heat demands.

With the advances in solar thermal utilization technology and the expansion of the market solar thermal utilization costs are expected to decline even further, particularly due to progress in solar heating and industrial-agricultural thermal utilization technologies. It is anticipated that in the medium and long term, the costs of solar hot water system will remain relatively stable. This will allow for rapid cost reductions in solar heating and cooling systems, as well as for industrial-agricultural thermal utilization.

Table 13-3 Projected costs of solar thermal utilization and application

Cost (RMB/W_{th})	2015	2020	2030	2050
Solar hot water system	2.14	2	1.71	1.71
Industrial-agricultural solar thermal utilization	1.71	1.43	1.43	1.43
Solar heating	4.29	2.86	2.86	2.86
Solar air conditioning	7.14	5.71	4.29	4.29

Development scale and distribution

In the Stated Policy scenario, by 2020, thanks to initial application of solar hot water systems, scaling up solar heating and industrial-agricultural thermal utilization systems to large-scale, and demonstration and application of solar air conditioners, installed capacity of medium and low temperature solar thermal utilization systems is expected to reach 512 GW_{th} (730 million m^2 in solar collector area)[53].By 2030 installed capacity of medium and low temperature solar thermal utilization systems will reach 746GW_{th},due to extensive application of solar hot water systems, large-scale application of solar heating and industrial-agricultural thermal utilization systems, and scaling up solar air conditioners to large-scale. By 2050installed capacity of medium and low temperature solar thermal utilization systems will reach 1,241GW_{th} following an all-round scale up of solar hot water systems, large-scale application of solar heating and industrial-agricultural thermal utilization systems, and large-scale promotion of solar air conditioners.

In the Below 2 °C scenario, solar thermal utilization and application fields will extend from domestic hot water to industrial hot water, building heating and regional heat supply. By 2020, widespread application of solar hot water systems, scaling up solar heating and industrial-agricultural thermal utilization systems to large-scale, and small-scale application of solar air conditioners, the installed capacity of medium and low temperature solar thermal utilization systems will reach 713 GW_{th} (800 million m^2 in solar collector area). By 2030, all-round scaling up of solar hot water systems, scaling up solar heating and industrial-agricultural thermal utilization systems to large-scale, and large-scale application of solar air conditioners, will result in the installed capacity of medium and low temperature solar thermal utilization systems reaching 1,202 GW_{th}. By 2050, scaling up combined solar hot water, space heating, and cooling co-generation systems to large-scale, and large-scale industrial-agricultural solar thermal utilization systems, will increase the installed capacity of medium and low temperature solar thermal utilization systems to 2,411 GW_{th}.

From a development distribution perspective, due to the varying heat demands of different Chinese climate regions, each climate region is different in terms of the scale of solar thermal utilization. Of all regions, the hot-summer and cold-winter region, covering most parts of China (including North, Central, East, and Northwest China), is a major area where solar thermal energy is utilized.

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[53] Installed capacity for each square meter of collector area is 700 W_{th}.

Table13-4 Installed medium and low temperature solar heating systems capacity in different climate regions (GWth)

	2020		2030		2050	
	Stated Policies	Below 2	Stated Policies	Below 2	Stated Policies	Below 2
Very cold	30	51	44	85	73	171
Cold	98	141	143	237	239	476
Hot summers and cold winters	337	460	491	775	817	1554
Hot summers and warm winters	42	51	62	87	102	174
Mild	4	11	6	18	10	37

13.3 Bioenergy outlook

China's bioenergy resources

Chinese biomass resources utilized for bioenergy are mainly made up of forestry, agricultural residue, municipal solid waste, and manure. Domestic sewage, industrial organic wastewater, and sludge also fall into the bioenergy resource category. However, wastewater and sludge is excluded from this report given the actual bioenergy utilization situation, sewage disposal technology, difficulties related to data and statistical analysis. Currently, the total theoretical bioenergy resource potential is approx. 1.61 billion TCE, of which 0.647 billion TCE can be utilized in the energy sector. In 2020, the total theoretical bioenergy resource potential will be approximately 1.741 billion TCE, of which 0.597 billion TCE can be utilized in the energy sector. In 2030, total theoretical bioenergy resource potential will be approximately 1.958 billion TCE, of which 0.533 billion TCE may be utilized in the energy sector. In 2050, the total theoretical bioenergy resource potential will be approximately 2.065 billion TCE, of which 0.356 billion TCE can be utilized in the energy sector.

Table 13-5 Development of available bioenergy resources

		2016			2020			2030			2050		
Category	Unit	Available	Used	Potential	Available	Used	Potential	Available	Used	Potential	Available	Used	Potential
Agricultural residue	Mton	630	300	330	630	300	330	630	300	330	630	300	330
Forestry residue	Mton	920	660	260	920	700	220	920	750	170	920	800	120
Municipal solid waste	Mton	190	90	100	277	240	37	369	325	44	409	367	42
Manure	Mton	1470	840	630	1700	1105	600	2100	1575	525	2300	2070	2300
Agricultural residue	Mtce	315	150	165	315	150	165	315	150	165	315	150	165
Forestry residue	Mtce	524	376	148	524	399	125	524	428	97	524	456	68
Municipal waste	Mtce	36	17	19	52	45	7	69	60	9	76	68	8
Manure	Mtce	735	420	315	850	553	300	1050	788	262	1150	1035	115
Total	Mtce	1610	963	647	1741	1147	597	1958	1426	533	2065	1709	356

Agricultural residue is mainly made up of crop straw. China's main crop production, planting structure, straw uses, and population size will remain relatively stable. This means that theoretical potential for crop straw residue yield is not projected to change significantly towards 2050. With continuous improvement of the collection systems and efficiency, crop straw available for energy utilization will be increasing. As a result, the amount of utilized straw is projected to increase accordingly in 2020, 2030 and 2050.

The types of forestry residues available for energy utilization mainly include wood fuel, forestry residues and residue from the forestry treatment industry. With rising ecological and environmental protection awareness, the logging will be reduced, which results in less residue resources. Residues from forest tending will however increase. Therefore, the total amount will remain mostly unchanged by 2050 compared to its current level. Total theoretical forestry residue resource potential will be approximately 0.524 billion TCE. Forestry residue utilization amounts will rise gradually as a result of improved processing and collecting technologies and increasing demands for clean heat. By 2050 0.14 billion tons of additional forestry residues will be used for heat supply compared with 2016, whilst 0.12 billion tons of forestry residues, equal to approximately 68 million TCE, are available for energy utilization.

Municipal solid waste is one of the bioenergy resources which will increase. With the growing Chinese urbanization, distribution and resource acquisition waste to energy projects will gradually move from large- and medium-sized cities to townships and counties. Starting with the current available waste amounts, projected urbanization rates, population development and a report from the World Bank[54]has been used to assess waste generation development. It is assumed that the municipal solid waste development towards 2050 in China will move towards the level of OECD countries in 2025.It is projected that during the 13th FYP period, municipal solid waste collected and available to the power and district heating sector will expand at an annual average growth rate of 5%. By 2020, collected municipal solid waste will reach 277 million tons/year, of which around 240 million tons, or 87%, is available for waste incineration power and heat generation. During 2020-2030, it is projected that China's municipal solid waste generation will slow down, expanding at an annual average growth rate of 3%. By 2030, it will reach approximately369 million tons, of which roughly 325 million tons or 88% of the collected amount, is available for waste incineration power and heat generation. From 2030 to 2050 municipal solid waste quantities continue to grow, albeit at a slow pace. By 2050 China's collected municipal solid waste amount to about 409 million tons/year, of which approximately367 million tons or 90% of the collected amount, is available for waste incineration power and heat generation.

Manure is one of the bioenergy resources with a relatively large development and utilization potential. Manure is mainly derived from three domesticated species; cattle, pigs, and chickens. With the development of social economy and improvement of people's living standards, it is projected that during 2016-2020, the scale of livestock breeding will grow at an annual average rate of 3%. By 2020, nationwide manure is estimated to reach 1.7 billion tons, equal to an estimated 0.85 billion TCE. During 2020-2030, the scale of livestock breeding will grow at an annual average rate of 2%. By 2030, nationwide manure resources are estimated to reach 2.1 billion tons, equal to approximately 1.05 billion TCE. During 2040-2050, nationwide manure will remain stable at 2.3 billion tons or roughly 1.15 billion TCE. Currently, manure treatment capacity is approximately 0.84 billion tons or around 57% of total manure resources. In 2020, manure utilization will rise to 1.1 billion tons, or 65% of total manure. In 2030, manure utilization will rise further to 1.575 billion tons or 75% of total manure resources. In 2050, manure utilization will rise even further to 2.07 billion tons or 90% of total manure resources. (After 2020 most collected manure will be utilized for biogas production.)

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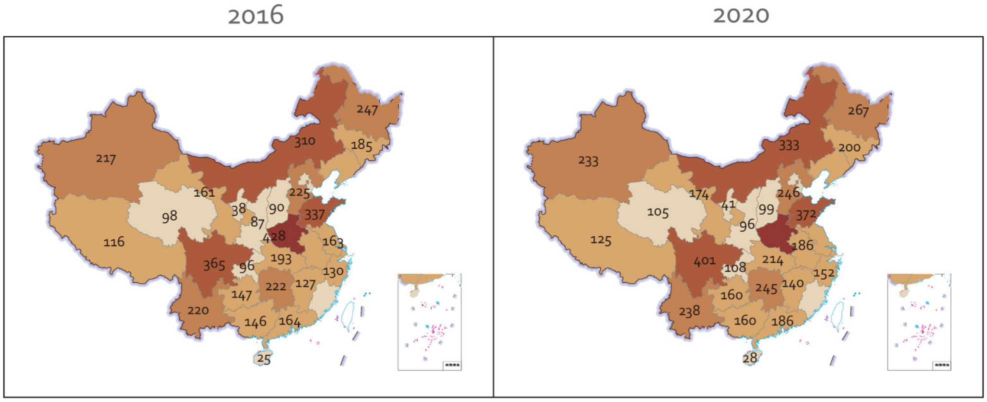
[54](Hoornweg & Bhada-Tata, 2012)

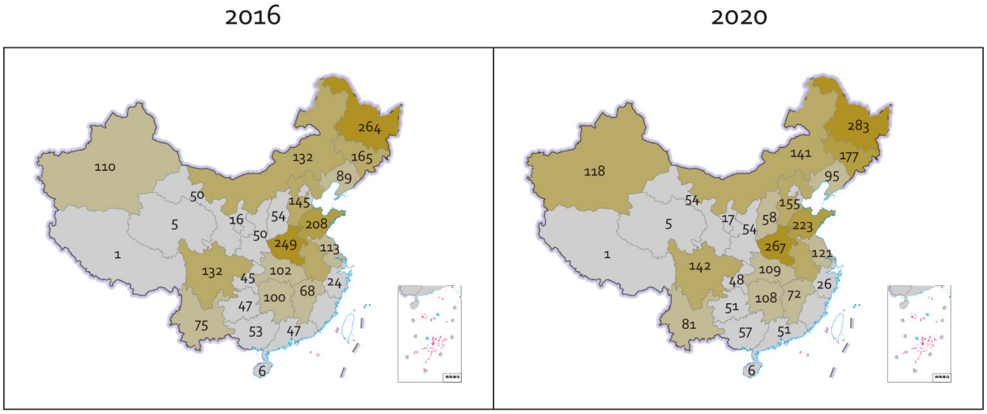
Bioenergy resources for power production

Figure 13-26 Municipal solid waste resources (PJ) by province in 2016 and 2020.



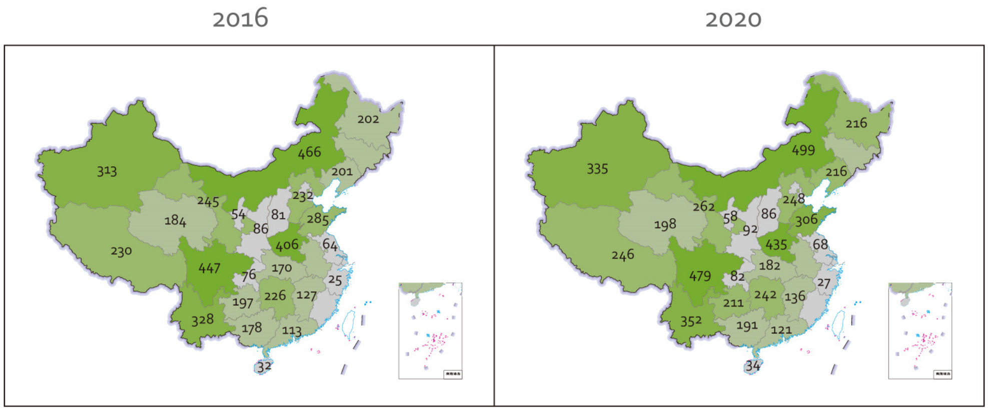
Waste resources available to the energy sector is estimated from the amount of waste generated on an either daily or annual basis from each Chinese province based on China's county-level population size and waste generation per person per day. Population data comes from China County-level Economy Yearbook 2013. Data concerning waste generation per person per day may differ from urban to rural areas. The average value is approx. 0.66 kg/person day in 2013. From a technical and economic feasibility perspective, based on the present power tariff subsidies and waste disposal fees, only counties (cities) which generate more than 300 tons/day are viable for setting up a waste to energy projects. In terms of regional distribution, without taking existing waste incineration power generation projects into account, Henan, Hunan, Hubei, Sichuan, and Chongqing are among the provinces or municipalities with a relatively big potential for new waste incineration power generation capacity from available resources.

Figure 13-27 Agricultural waste resources (PJ) by province in 2016 and 2020.



For crop straw resources, it is estimated that China's theoretical potential is around 630 million tons, equal to approximately 320 million TCE. This is based on the yields of corn, rice, wheat, potato, cotton, peanut, and rapeseed and the corresponding ratios of output of main product to by-product of the crops[55] as revealed in China Statistical Yearbook 2016.Crop straw resources are mainly distributed in 13 grain-producing provinces (regions), including the North China Plain, the Middle-Lower Yangtze Plain and the Northeast Plain. Analysis of straw utilization reveals that roughly 15% of total straw resources are utilized as fertilizer for farmland, while approximately 24% and 3%, respectively, are used for feedstuff and paper making.43% of total straw resources are used as direct household fuel combustion and about 15% is burned in fields. Crop straw resources available for energy utilization total at about 330 million tons. These are mainly from household fuel and direct burned in fields.

Figure 13-28 Resources for biogas production (PJ) by province in 2016 and 2020.



Based on the estimated manure quantities in the China Statistical Yearbook 2016, which is in accordance with the livestock breeding situation, the amount of manure nationwide is around 1.47 billion tons. Currently, available manure recourses used as fertilizer is around 0.84 billion tons. Manure resources available for biogas generation is around 0.63 billion tons this could be used to produce around 35 billion m^3 biogas. Judging from the present livestock breeding distribution, there are three provinces, namely Sichuan, Inner Mongolia and Henan, where the manure quantities exceed 100 million tons. In Yunnan, Xinjiang, Shandong, Gansu, Hunan, Hebei, Tibet, Liaoning, Heilongjiang, Guizhou and Guangxi, the amount of manure exceeds 50 million tons.

In biogas generation, a combination of factors, such as regional manure and crop straw resource reserves, competing utilization pathways, like uses as fertilizer, feedstuff, raw material as well as other factors, including regional climate differences, biogas development, economic level, and clean energy demand, have to be carefully considered. Currently, the amount of manure available for biogas generation is around 270 million tons.

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[55] (NEA, 2012)

By 2020, manure utilization amount is expected to reach approximately 350 million tons, which is enough to produce 20.7 billion m^3 of biogas.

Bioenergy in the power sector

Power currently generated from forestry and agricultural residues

By the end of 2016, the installed capacity for grid-connected forestry and agricultural biomass power generation reached 6.05 GW, accounting for about 50% of total installed bioenergy power generation capacity. Most agricultural and forestry biomass power plants are located in North, Northeast, Central and East China, areas with rich crop straw resources. These regions have approximately 94% of the nation's total installed capacity for forestry and agricultural biomass power generation. In the southwest region crop straw resources are in short supply, and the mountainous terrains cause difficulties in raw material collection and transportation. The southwestern climate is hot and humid all reasons to limited use of biomass for power generation, with 5% of China's installed capacity. In China's north-western region there are few straw resources leading to the very limited use biomass for power generation. After 2020, all new forestry-agricultural direct-fired biomass power generation projects will be combined heat and power (CHP) plants.

Capacity and generation development

Figure 13-29 National bioenergy capacity development (GW) for the two scenarios.

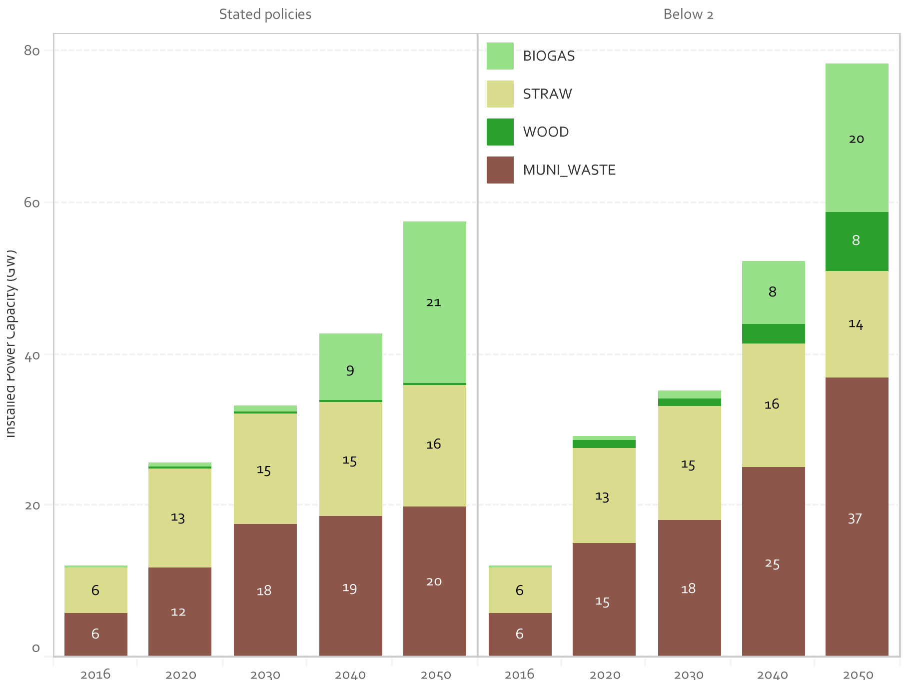
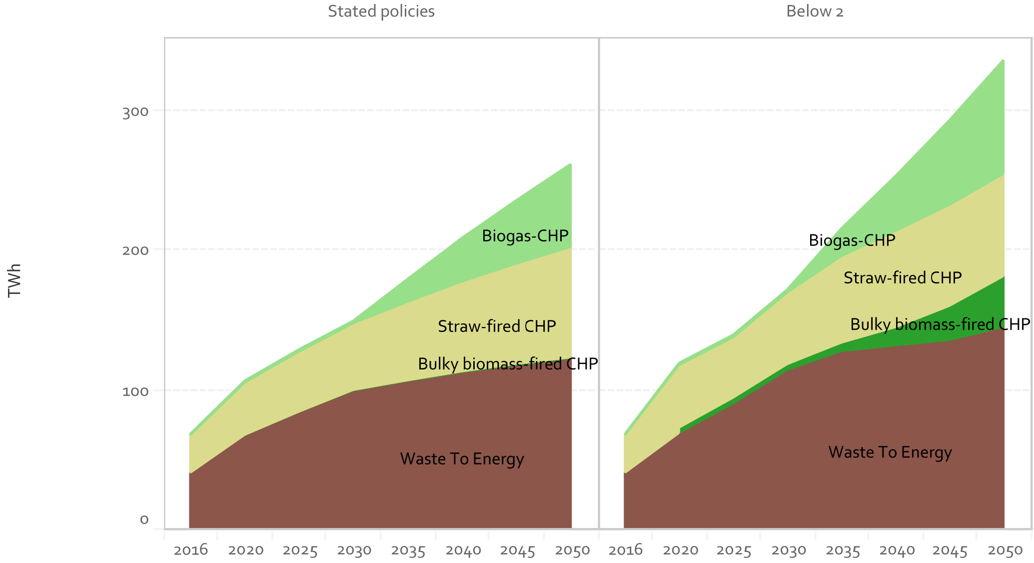


Figure 13-30 National bioenergy generation development (TWh) for the two scenarios.



	2016	2020	2030	2040	2050	2016	2020	2030	2040	2050
Grand Total	**67**	**106**	**149**	**208**	**261**	**67**	**118**	**171**	**252**	**335**
Biogas-CHP	1	1	2	31	59	1	2	2	39	82
Bulky biomass-fired ..		0	0	0	1		4	4	13	36
Straw-fired CHP	27	37	48	64	79	27	45	51	69	73
Waste To Energy	40	67	99	112	122	40	68	113	131	144

The Stated Policy scenario:

- By 2020, 2030, 2040 and 2050, total installed bioenergy power generation capacity will reach 26GW, 33GW, 43GW and 57GW, respectively. Total electricity output will reach 106TWh, 149TWh, 208TWh and 261TWh, respectively.
- Direct-fired power generation from forestry-agricultural residues will remain at the 2020 level. From 2017 to 2020, projects with favourable conditions should shift to a CHP approach wherever possible. No new power-only projects will be approved and after 2030, all new projects will be CHP plants.
- In the future, forestry-agricultural biomass power generation projects will be CHP projects, using either pure biomass fuels, or co- firing of biomass and coal. After 2020, CHP plants using co-firing of biomass and coal will be a key source of growth in addition to the targets set out in the 13th FYP. Installed co-firing plant capacity will reach 5GW. During 2030-2050, biomass co-firing plant capacity will remain on par with that direct-fired biomass power plants, with total installed

capacity around 16GW.

- Waste to energy plants will develop rapidly. In the stated policies scenario China's waste to energy capacity will increase to 12GW by 2020, and further to 18GW by 2030. After 2030, with China's urbanization process will start to slow down and installed waste to energy capacity will gradually decelerate. By 2050, installed capacity of waste incineration plants will reach approx. 20GW.

The below 2 degrees Celsius scenario

- Under the Below 2 °C scenario, installed direct-fired biomass power generation capacity will not change significantly compared to the Stated Policies scenario. This is due to its low overall efficiency and the steady trend towards CHP generation.
- In order to effectively replace fuel coal and reduce GHGs, co-firing biomass with coal for power generation (including CHP generation) will be vigorously promoted.
- Compared to the Stated Policy scenario, changes in bioenergy power generation growth will mainly come from biogas CHP and waste to energy.

Limited available bioenergy resources and limited competitive technological advances in bioenergy will drive bioenergy raw material utilization from power generation to other fields, like biogas and biofuel. By 2020, 2030, and 2050, total installed bioenergy power generation capacity will reach 29GW, 35GW and 78GW, respectively.

Bioenergy power and CHP generation technology

Bioenergy CHP power generation refers to combined heat and power generation technology using bio as fuel; in other words, it is a technology enabling power generation, whilst residual heat is used for heat supply. The use of heat or electricity depends on bioenergy fuel type and end user demand. Implementing CHP generation may significantly increase system efficiency, save energy and reduce emissions. Bioenergy CHP generation as a mature technology mainly includes three types of technologies: steam extraction, low vacuum heating, and absorption heat pumps. Transforming present biomass-based power generation projects into biomass CHP projects would bring about a 10-15% increase in energy utilization efficiency. To minimize transformation costs and utilize energy efficiently and economically, this should be carried out in selected industrial production areas, commercial, and residential areas with stable heating demand. Regarding new CHP projects, local resource conditions and the region's heat supply and demand should be considered. Different technologies should be formed to suit the local characteristics.

Compared to its bioenergy power generation industry, China is still lagging far behind in the development of bioenergy CHP generation. In 2015, installed capacity of bioenergy power plants equipped with CHP generating units was around 1.7GW, accounting for 14% of total installed bioenergy power generation capacity. Bioenergy CHP plants are mainly concentrated in the northeast and north regions, which have high heating demand during winter, and the economically developed Jiangsu-Zhejiang region which have high industrial heat demands. Of the existing bioenergy CHP projects, some bioenergy power plants, albeit already equipped with CHP generating units, have not implemented CHP generation because of reasons such as low local heat prices and unstable raw materials supply. Guangxi has the largest sugar-making base and sugarcane bagasse resource. It is also the region with the most installed bioenergy CHP generation capacity in China. To take full advantage of its rich bagasse resource, the province launched a CHP transformation and upgrading project of old and used sugar mill boilers and power generating units. The installed capacity of bagasse-fired CHP capacity currently exceeds 1 GW and is expected to increase.

The application of CHP waste to energy plants is also in a start-up stage. Of the 224-existing waste to energy plants, only a few are in good condition and have successfully implemented CHP generation, primarily for industrial heating. Residential heating is mainly supported by fluidized bed boiler co-fired with coal. Currently, there are only 33 waste incineration CHP projects in China, which make up less than 15% of all completed projects.

Forestry-agricultural biomass CHP plants are suitable for district heating use in cities and townships, as well as in small industrial parks and clusters. Compared to pure power generation, comprehensive thermal efficiency of forestry-agricultural biomass CHP generation may increase by 20-25%. Therefore, the government supports the development of forestry-agricultural biomass CHP generation in a bid to increase biomass resource utilization efficiency. All new bioenergy power generation projects, if having proper technical and economic feasibility conditions, are required to implement CHP. In addition, the government incentivizes existing bioenergy power generation projects, to implement CHP in accordance with the heat supply market situation and their technical and economic feasibility conditions.

Biomass for heating

Biomass heating boiler technology

Biomass boilers refers to heating boiler using biomass fuel as raw material. Biomass boilers are used for a wide array of purposes. A biomass boiler may either be built from scratch, or transformed from an existing coal-fired boiler. Biomass boilers can be flexibly deployed and have a wide application range. Biomass boilers are mainly used to replace coal-fired boilers used for district heating, or for providing heat to the agricultural product processing industry (drying grain, vegetable, tobacco, etc.), facility agriculture (greenhouses), the breeding industry, hospitals, schools, and public building facilities, or for industrial enterprise production like iron and steel smelting, or meeting household energy demands, e.g. residential heating and domestic hot water. Of all projects currently in operation, the largest one, which has a capacity of 56 MW_{th}, consumes 100,000 tons of briquette fuel per year, and supplies half a million-ton steam per year. Of all projects currently under construction, the largest one has a capacity of 84MW_{th}, and is mainly supplying district heat for industrial parks.

Biomass boiler heating may be divided into three types; biomass briquette boiler heating, biomass pellet boiler heating, and forestry-agricultural biomass residue direct-fired boiler heating. In China, briquette and pellet boiler heating methods are widely adopted. In Europe, pellet boiler heating is the dominant technology. In North European countries like Denmark, direct-fired boiler heating from forestry-agricultural residues is the prevailing method. Currently, China's forestry-agricultural biomass residue direct-fired boiler heating technology is still immature. Hence, the technological level of the entire industrial chain, starting from collecting raw materials, storage and transportation, standard formulation to equipment manufacturing, is yet to be further developed. Scaling up biomass heating boiler technology is primarily dependent on the heat price, economic efficiency of the boiler, and price of raw materials. Biomass pellet and briquette production technology is very mature, in regions with high clean energy demands due to coal restrictions, biomass and briquette fuel might be the best alternative to coal. However, in regions where coal prices are relatively low, pellets and briquette fuel may not have very good price competitiveness.

Table 13-6 Investment cost for bioenergy power generation and heating technologies (million RMB/MW)

	CHP			**Direct-fired power generation**	**Heat-only boiler**
	Biogas	Forestry-agricultural residue	Municipal solid waste	Forestry-agricultural residue	Forestry-agricultural residue
2016	5.0	9.2	19.4	8.7	1.8
2020	5.0	9.2	16.2	8.7	1.8
2030	5.0	9.2	13.5	8.7	1.8
2040	5.0	9.2	13.5	8.7	1.8
2050	5.0	9.2	11.3	8.7	1.8

Table 13-7 Generation efficiency of bioenergy power generation and heating technology systems (%)

	CHP			Direct-fired power generation	Heat-only boiler
	Biogas	Forestry-agricultural residue	Municipal solid waste	Forestry-agricultural residue	Forestry-agricultural residue
2016	92%	28%	22%	28%	92%
2020	92%	31%	24%	31%	92%
2030	92%	33%	25%	33%	92%
2040	92%	33%	25%	33%	92%
2050	92%	38%	26%	38%	92%

The future development scenario mainly involves three types of technologies; the present bioenergy direct-fired power generation (pure power generation), CHP and biomass heating. CHP technology may be further divided by fuel into; biogas CHP, agricultural residue CHP, forestry residue CHP, and municipal waste CHP. In the model, raw materials used by biomass heating boilers may be divided into two types: agricultural and forestry residues. The model makes predictions on a number of key parameters, such as system power generation efficiency and investment costs per unit of installed capacity. This is based on different types of technologies, technological advances in different development stages, fuel availability, and changes in factors affecting economic efficiency. Table illustrate investment cost and efficiency changes.

Table 13-8 Installed heat capacity (GW)

	Stated policies					Below 2				
	2016	2020	2030	2040	2050	2016	2020	2030	2040	2050
Grand Total	**10**	**50**	**81**	**83**	**106**	**10**	**90**	**122**	**259**	**398**
BIOGAS	0	1	1	8	20	0	1	1	8	18
STRAW	9	34	48	42	40	9	38	55	67	92
WOOD		3	8	7	5		33	41	145	213
MUNI_WASTE		12	24	26	40		19	25	39	75

Table 13-9 Heat generation (PJ)

	Stated policies					Below 2				
	2016	2020	2030	2040	2050	2016	2020	2030	2040	2050
Grand Total	34	899	1.283	1.299	1.505	34	1.846	1.441	3.081	4.335
BIOGAS	4	6	7	105	200	4	6	8	134	275
STRAW	30	552	687	708	740	30	650	822	1.017	1.284
WOOD		66	122	119	86		750	547	1.930	2.775
MUNI_WASTE		275	468	367	479		441	64		

Table 13-10 Heat only boiler installed capacity and generation in the two scenarios.

		Stated policies				Below 2			
		2020	2030	2040	2050	2020	2030	2040	2050
Installed Heat Capacity (GW)	STRAW	15	27	20	19	19	33	44	74
	WOOD	2	8	7	5	32	39	142	202
Heat Generation (PJ)	STRAW	340	383	333	322	377	497	589	891
	WOOD	65	120	117	83	726	521	1.852	2.565

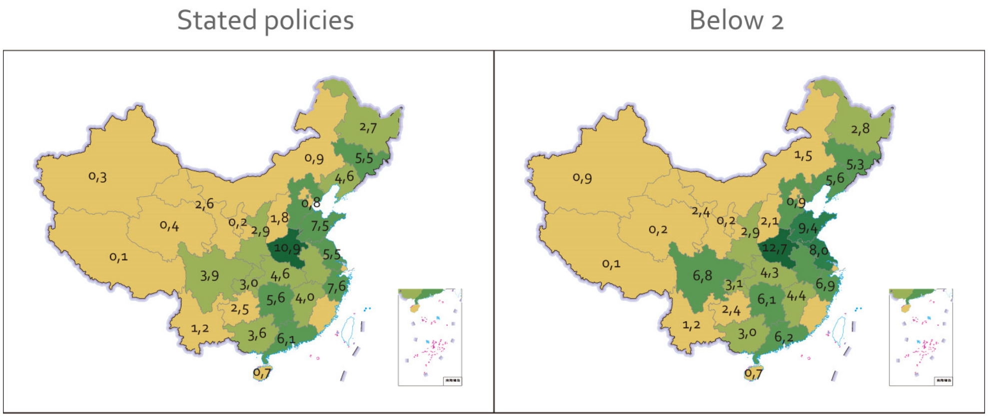
The stated policy scenario

From an energy application perspective, the model considers regional heating, heat supply and demand, as well as the heat supply capacity from biomass raw materials. Compared to national policy targets, the heating installation capacity in the stated policy scenario is a bit conservative, with the amount of bioenergy raw material consumption being 11 million, 12 million and 32 million tons in 2020, 2030 and 2050, respectively.

The Below 2°C scenario

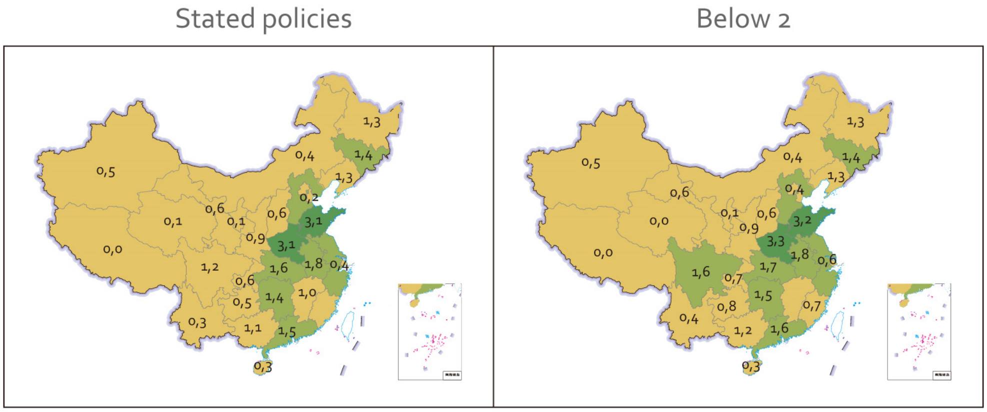
In the Below 2°C scenario, the model fully explores the development potential of forestry bioenergy resources, and suggests a rising role of biomass heating in district heating and industrial production. The Below 2°C scenario shows that biomass holds huge potential for heating in the future. This, however, depends on the development of forestry residue resources. In 2020, the amount of bioenergy resource consumption will reach 78 million tons, of which 60 million tons are derived from forestry biomass sources. In 2030, the amount of bioenergy resource consumption will be around 82 million tons, the growth of which mainly comes from agricultural residues. By then, with gradual improvement of the forestry and agricultural residue collecting system and handling systems, the amount of collectible and utilizable biomass resources will increase significantly. During 2030-2050, bioenergy utilization is expected to witness exponential growth. By 2050, forestry and agricultural residue collection and utilization will peak at 340 million tons, equal to 170 million TCE, of which the amounts of agricultural and forestry residues are around 70 million and 270 million tons, respectively.

Figure 13-31 Generated power (TWh) from bioenergy resources in 2020 in the two scenarios.


Stated policies

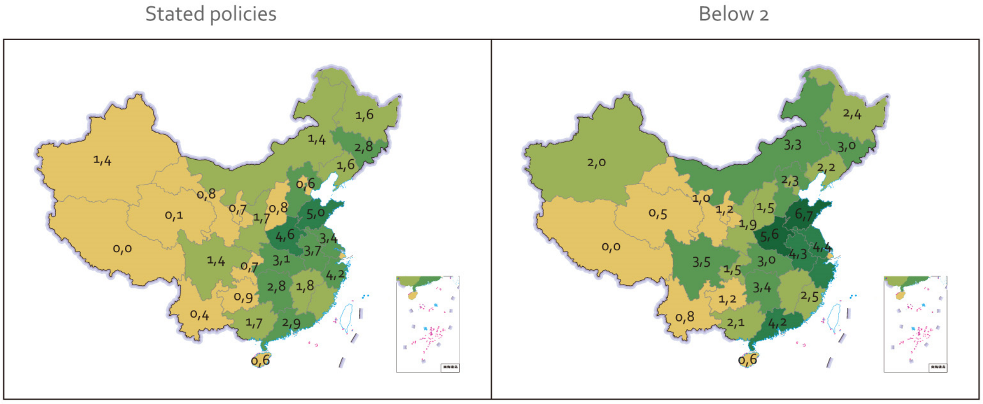
Below 2

Figure 32 Installed bioenergy capacity (GW) in the two scenarios in 2030.


Stated policies

Below 2

Figure 13-33 Installed bioenergy power capacity (GW) in 2050 in the two scenarios.



Stated policies

Below 2

Biomass for district heating and individual heating

The stated policy scenario:

The main sources of biomass used for heating are forestry-agricultural residues. Heating for rural residents depend on agricultural residues and account for 30% of utilized amounts, while fuel for industrial and district heating mainly comes from forestry residues, accounting for 70% of total utilization amount. According to current application status of biomass heating around 6.6 million TCE, will be used for industrial heating by 2020.

During 2020-2030, biomass heating will continue to maintain rapid growth. With a basically mature biomass resource collecting system in place, biomass resource utilization will amount to 50 million tons, of which fiber-based agricultural residues makes up around 30%, and wood-based forestry residues and urban building waste make up around 70%. By 2030, the amount of biomass used for heating will reach 16 million TCE.

The 2030-2040 period will have steady growth in biomass heat supply, and more rational resource allocation and heat supply distribution. In view of resource availability and the development of competing heat supply technologies, biomass resource utilization will peak during this period. By 2040, the amount of biomass used for heating will reach15million TCE.

In 2050, biomass heat capacity will be gradually reduced as biomass resources will used for higher value products and resources will be utilized more efficiently.

The Below 2°C scenario

The heat demand for buildings in China is tremendous at 300 million TCE annually. District heating for urban citizens makes up approximately 2/3, and heat supply for rural residents approximately 1/3. In the industry about350GW$_{th}$ of boiler heat supply capacity, equal to

300 million TCE, or the entire heat demand for buildings, needs to be replaced or transformed by 2020. In the Below 2°C scenario, bioenergy will provide a maximum of 50 million TCE by 2020, equal to 70GW of boiler heating, or less than 10% of heat demands. This shows opportunities for bioenergy use in heat supply to be developed in the future.

Driven by government subsidies and environmental concerns, biomass heat supply capacity is expected to substantial increase by 2030.Most growth will come from residential heating in rural areas and substitution of industrial boilers. The substitution of coal-fired industrial boilers and district heating will continue to increase towards 2040 and 2050.By then, biomass heat supply is expected to reach 29 million TCE, consuming about 58 million tons of biomass resources each year.

Table 13-11 Development of biomass for district heating and individual heating in the two scenarios.

		Stated Policy				Below 2°C			
		2020	**2030**	**2040**	**2050**	**2020**	**2030**	**2040**	**2050**
Heat supply	Mtce	6.62	16.24	15.39	6.71	6.51	35.53	36.02	28.82
Resource consumption (straw)	Mton	13.24	32.48	30.78	13.42	13.02	71.06	72.04	57.64

Biofuels

Biomass for biofuels, including transformation losses

The Stated Policy scenario:

The development of liquid biofuels is correlated with biomass resource logistics, technological R&D and strength of policy support. Under current resource conditions, technical levels and policy system, it is very challenging to achieve the target of 6 million tons of produced biofuels by 2020, as specified in the *13th FYP for renewable energy development*. However, this target is achieved in both scenarios.

Regarding resources for the ethanol fuel industry, apart from the existing 2 million tons/year production capacity of aged grain ethanol (corn ethanol), future additions will mainly come from non-grain crops, forestry and agricultural residues or energy crops. For the biodiesel industry, with gradual improvement of the waste oil collection system, the 2 million tons/year development target for 2020 will be met. Future growth will be largely dependent on factors such as crop planting technique, marginal land development, utilization rate and the scale of energy crop market development.

Second-generation biofuel technology is still facing a whole slew of technical challenges on its way to commercialization. Complicated production conditions and lack of data to assess the status of industrialization mean that costs are reduced at a slow pace in the scenarios. Decreases in fossil-based transport fuel prices and the emergence of electric vehicle technology have affected the development of the liquid biofuel industry, leaving its technical and economic competitiveness at a standstill.

Recently policy support for production has been weakened and there have been restrictions on the application market. Policy support from competent departments and market coordination is vital for the future development of biofuels. Establishing relevant standards for liquid biofuels usage, setting up related testing certification systems and supervision platforms will be key in the development of the biofuel industry.

The Below 2°C scenario

In the Below 2°C scenario, with the assumption that various technical routes for biofuel production currently are quite mature, marginal land development and utilization efficiency is significantly enhanced and all links along the raw material supply chain are connected. The production will increase over time as shown in Table.

In the Below 2°C scenario, large-scale commercialization of ethanol fuel is realized using crops like sugar and sweet sorghum as raw materials. Microbiologic fermentation techniques with high temperature resistance, high ethanol concentration and high permeability features are applied. Non-phase ethanol separation techniques are adopted. Economic competitiveness of ethanol is continuously enhanced. Ethanol production techniques by co-fermentation of hexose and pentose will experience a breakthrough. Cellulosic ethanol gains access to the production arena. Energy crops with high barren resistance is planted at large scale in saline alkaline land and sandy wastelands. Techniques for increasing the starch content of starch crops and the sugar content of sugar crops are successfully developed. Breakthroughs are made in the planting of shrubs and grass varieties with high yield, wind and sand resistance, as well as aridity resistance by 2030.A complete bioenergy resource database is created. Available land resources are further developed. Utilization of forestry-agricultural residue resources are strengthened. Large-scale application of the second-generation ethanol fuel becomes a focal point of biofuel industry development. This all leads to biofuels becoming a major alternative to fossil fuels.

In the long run, ethanol fuel technology using non-grain grains (e.g. sweet sorghum, cassava and sweet potato) as raw materials will be fully mature and production technologies for cellulose-based ethanol fuel fully commercialized. The focus will shift to make marginal land development more effective. Closer attention will be paid to rational industry planning and distribution. Under the premise of placing equal emphasis on energy supply ratio, environmental protection, and energy conversion efficiency, by 2050, ethanol fuel production capacity will increase to 20 million TCE.

Whilst traditional biodiesel with animal and plant oil as raw materials is being developed and utilized, other biodiesel production technologies, such as Fischer-Tropsch diesel and pyrolysis gasoline, which helps to further increase their substitution ratio to fossil diesel. Direct biomass liquefaction technology enters a demonstration stage. Technological barriers in algae biodiesel and hydrogenated biodiesel will be fully overcome. Shrubs and grass varieties with high yield, wind, sand, and aridity resistance, are planted at a large scale. The choices of biodiesel raw materials are more diversified. With large-scale cultivation and development of algae and oil plant energy forests, total biodiesel production capacity will reach up to 36.5 million TCE.

Table 13-12 Biofuel development in the two scenarios (Mtce)

		2020	2030	2040	2050
Stated Policy Scenario	Ethanol	0.13	0.5	1.96	8.93
	Biodiesel (road)	5.95	9.74	15.32	23.58
	Bio jet fuel (air)		9.24	29.84	46.11
	Total	**6.08**	**19.48**	**47.12**	**78.62**
Below 2° C scenario	Ethanol	0.2	1.04	4.25	19.25
	Biodiesel (road)	6.44	13.53	23.26	36.52
	Bio jet fuel (air)	0.24	11.78	37.29	57.25
	Total	**6.88**	**26.35**	**64.8**	**113.02**

13.4 Hydropower Outlook

Hydropower development situation in 2016

China has become a world leader in the number of dams built and installed hydropower capacity. In terms of dam design and construction expertise, China also occupies a leading position in the world. In 2016 China experienced steady and rapid development of the hydropower industry, just as in past years. Recently installed and total hydropower capacity (excluding pumped storage) nationwide reached approximately 10 and 305 GW, respectively, with the latter accounting for 1/4 of total installed hydropower capacity worldwide. 11 new major hydropower projects were approved and began construction, with their total installed capacity amounting to 15.7 GW.

Throughout 2016, China's hydropower, apart from steady development, demonstrated some new characteristics. With China's economic growth mode entering a "new normal", significant changes are taking place in the electric power market. Whilst social electricity consumption and demand decreases, the growth in installed thermal power capacity remains robust, making the supply-demand imbalance of electricity even worse and directly leading to frequent occurrence of hydro, wind and solar power curtailment. While hydropower construction and operation scale starts to decline in China, a transition of development focus is on the way. Construction of the "West-East Power Transmission Project" base has officially commenced. Hydropower construction projects are gradually moving towards the southwest region where geographical and climatic conditions are more complicated. This raises engineering safety requirements, not to mention significant cost increases that lead to poor economic efficiency of hydropower, and the ever-increasing technical difficulties to overcome due to high altitude, complicated geological structure. All these result in a big challenge for safety and risk aspects of construction work.

Despite the fact that China's hydropower development expands at a continuously-increasing magnitude for many years, and that hydropower now accounts for about 40% of total electricity production of the country's technically feasible resources, it still holds huge development potential. China's *13th FYP for hydropower development*, which was released in 2016, suggests that the five years during the period 2016-2020 will see an addition of 60 GW in conventional hydropower and pumped storage capacity. Adding to this the 13thFYP further says that 60 GW of conventional hydropower and 60 GW pumped storage hydro should be under construction in 2020.

By 2020, China's total installed hydropower capacity is expected to reach 340 GW. Hydropower stations are capable of generating 1250TWh of electricity per year, equal to approx. 375 million TCE, making hydropower take up a 50% plus share of non-fossil energy consumption. The plan explicitly proposes that in the future, the capacity of the "West-East Power Transmission Project" be continuously expanded until it reaches the level of 100 GW by hydropower alone in 2020.In 2025, China's installed hydropower capacity is expected to reach 380 GW. Annual hydropower production will reach 1400TWh.

Technical and economic characteristics of hydropower

China's water resources examination survey 2015 shows that there are 3,880 rivers with a theoretical hydropower resource potential of at least 10 MW in mainland China. These theoretical hydropower resources are capable of generating 6082.9 TWh of electricity per year, with their average power being 694.4 GW; technically feasible resources will have an installed capacity of 541.6 GW, capable of generating 2474 TWh of electricity per year; and economically feasible resources will have an installed capacity of 401.7 GW, capable of 1753.4 TWh of electricity per year. In 2016, the installed capacity accounted for 78.0% of China´s total technical and 57.9% of China's total economically feasible potential resources. In terms of electricity generation, hydropower generation accounted for 40.7% of China´s total technical and 28.8%of China's economically feasible potential in 2016. From the perspective of theoretical potential, technically, and economically feasible hydropower resources, China occupies a leading position in the world.

According to the preliminary study, the national pumped storage economic development capacity of about 137GW.The resources are mainly distributed in North and South China, which accounts for about 40% of the total amount of resources.

Geographically speaking, China's hydropower resources are unevenly distributed. Hydropower resources are abundant in the west, but scarcer in the central and eastern parts of China. Of all regions, the southwestern region (including Sichuan, Chongqing, Yunnan, Guizhou and Tibet) has the most hydropower resources in China. Technically feasible resources of this region account for 66.7% of the national total.

In accordance with the distribution characteristics of the country's hydropower resources, China has rolled out a plan to build 13 large-scale hydropower bases along the upper reaches of the Yangtze River, Jinsha River, Dadu River, Yalong River, Wu River, Nanpan and Hongshui Rivers, Lancang River, the upper reaches of the Yellow River, north mainstream of the Yellow River, Northeast China, West Hunan, Fujian-Zhejiang-Jiangxi and Nu River.

Table 13-13 Summary of hydropower resources nationwide

Theoretical potential	Installed capacity (GW)	**694**
	Electricity generation (TWh)	6082.9
Technically feasible resources	**Installed capacity (GW)**	542
	Electricity generation (TWh)	2474
Economically feasible resources	**Installed capacity (GW)**	402
	Electricity generation (TWh)	1753.4

***Data source**: results of national water resources re-examination survey released in 2005.The range of survey data includes rivers with a theoretical potential of over 10,000 kW and all power stations that are located on these rivers and have an installed capacity of 50 million kW or above.*

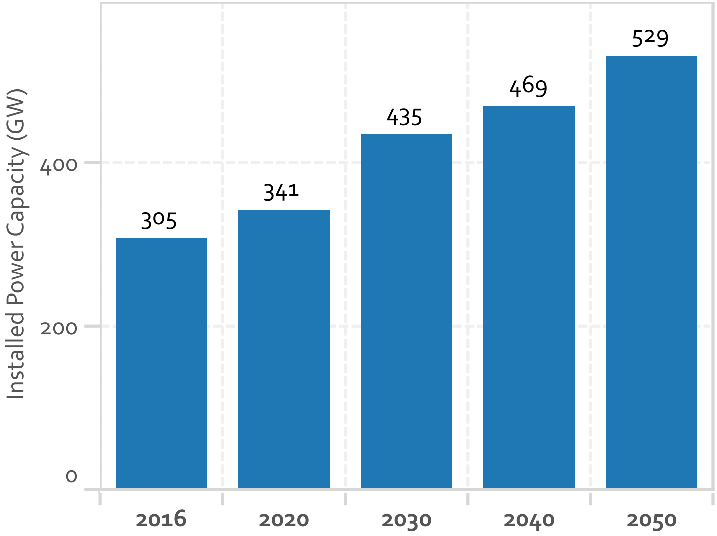
Judging from geographical distribution, the southwest region is where hydropower resources are the most abundant in China. The region's theoretical potential accounts for 70.6% of the national total. In comparison, the economically developed East and South-Central China (including South China) account for merely 4% and 8.6%, respectively. By province, three provinces/region, i.e. Tibet, Sichuan and Yunnan, have the most abundant hydropower resources in China, with their average power of theoretical potentials being 201, 144 and 104 GW, respectively, which account for 30%, 20.7% and 14.6%, respectively, of the national total.

Judging from distribution of installed capacity scale, of all technically feasible hydropower resources in China, large-sized hydropower stations have an installed capacity of 388.7 GW, accounting for 72% of the total; middle-sized ones have an installed capacity of 87.7 GW, accounting for 16%; and small-sized ones have an installed capacity of 65.21 GW, accounting for 12%.Of all economically feasible hydropower resources, the proportions of hydropower stations of various types are basically in tandem with those in the case of technically feasible hydropower resources.

Roadmap for hydropower development

China will adhere to the redlines of ecological protection and ensure hydropower development targets are met. For pumped storage development is covered in chapter 11.5 and will not be expanded on further in this chapter. The main factors affecting hydropower development have turned from economic and technical into environmental protection and involuntary displacement. This is especially true over the past few years when the effects of hydropower development on ecological environment and displacement of people are drawing increasing public attention. In spite of constantly raised compensation standards for people displaced from new hydropower projects, settlements have become even more difficult due to lack of sufficient attention to personal interests and increased expectation towards settlement. Moreover, with unprecedented levels of environmental awareness, people have also raised even higher environmental requirements on hydropower development.

Figure 13-34 Hydropower capacity development in the scenarios.



Hydropower is the key to success in China's clean and low-carbon power development and will remain the clean and low-carbon technology with the largest share in China's power mix before 2030. To realize energy transformation and development targets, by 2020, conventional hydropower capacity must reach 340 – 360 GW, and hydropower as a share in China's clean and low-carbon power generation structure must exceed 50%.

Before 2030, the construction of large-scale hydropower bases should continue to be pushed forward. By mainly developing rivers with plentiful and concentrated hydropower resources, several large-scale hydropower bases will be constructed. Considering the relatively long construction cycle of hydropower development and renewable energy development targets, our focus will be put on advancing hydropower development in such river basins as the upper reaches of the Jinsha River, Yalong River, Dadu River, the middle and lower reaches of the Lancang River, the upper reaches of the Yellow River and the middle reaches of the Yarlung Zangbo River. Meanwhile, China will commence hydropower development in such river basins as the upper reaches of Jinsha River, the upper reaches of the Lancang River and the Nu River. By 2030, total installed capacity of conventional hydropower stations will reach 430-470 GW. After 2030, the main focus of China's hydropower development will be shifting to the main stream of the Yarlung Zangbo River located in southern Tibet and the Tibet Autonomous Region. Whilst more stringent environmental protection standards are met, installed conventional hydropower capacity is expected to reach 520 GW or above in 2050.

Development orientation

Hydropower is a clean renewable energy source that is technologically mature, economically feasible and viable for large-scale development. Utilizing hydropower resources is of great significance to safeguarding national energy security, optimizing the energy mix, reducing pollutant and GHG emissions and promoting regional coordinated development. Strategic positioning of China's hydropower development includes the following several aspects:

(1) Conducive to improving China's energy supply capability and optimizing the energy mix.

Currently, hydropower remains a renewable energy source with the most mature technologies and the biggest advantage in scale development and utilization. Being the country with the largest hydropower resource potential in the world, with the development of economy and society, the series of challenges China is now facing, such as energy resource shortage, irrational energy mix, environmental pollution and GHG emissions reduction, will become even more prominent. Development of hydropower resources, however, may help alleviate China's energy supply shortages and further optimize its energy mix.

(2) Conducive to advancing the development of China's west region and promoting coordinated development of regional economy.

Despite being relatively underdeveloped, West China has plenty of hydropower resources. Hydropower resources of the 12 western provinces (autonomous regions and municipalities directly under the central government) account for approx. 79.3% of the national total. Most of the hydropower resources are concentrated in Sichuan, Yunnan, Tibet, Guizhou, Guangxi, Qinghai and Chongqing. Currently, total exploited hydropower capacity of the west region accounts for merely 10% of its technically feasible hydropower potential. Hence, the west region holds huge potential and has broad prospects for hydropower development.

(3) Conducive to overall planning and achieving maximum comprehensive utilization benefits from water resources.

Aside from power generation, hydropower projects have other comprehensive utilization benefits as well, including flood prevention, irrigation, water supply, shipping, tourism and ice prevention.

Development thoughts

With the scientific developing conception being our guidance, preserving the ecological environment, properly proceeding with settlements for displaced people, and reducing farmland inundation being the preconditions, placing equal emphasis on economic and social benefits and giving preference to social benefits being the principle, and safeguarding energy security and optimizing the energy mix being our starting point, we will make overall arrangements to watershed water resources development and planning, make deployment in a scientific way, intensify development efforts in key watersheds, push forward hydropower base development bearing in mind such elements as "watershed, volume, continuity, rolling-over and orderliness", strengthen capacity building for the "West-East Power Transmission Project", and strive to achieve optimal resource allocation and ensure energy security.

Geographical distribution

By hydropower development level and surplus resource distribution characteristics, China may be divided into three zones: *deep development zone*, referring to a region with its development level exceeding 80% and with little development potential; *optimal development zone*, referring to a region with its development level below 50%, the surplus hydropower resources mainly distributed in main river streams and overall good conditions for development. This zone mainly covers four provinces/regions, i.e. Qinghai, Sichuan, Yunnan and Tibet; and *key development zone*, referring to key Chinese regions for future hydropower development. The development scale of key development zones for 2020, 2030 and 2050 will account for 54%, 63% and 68%, respectively, of then total national installed capacity. Among them, Sichuan, Yunnan and Tibet are expected to maintain a hydropower development scale of 100 million kW or above, in 2050.

Figure 13-35 China's hydropower development distribution in 2030 (GW)

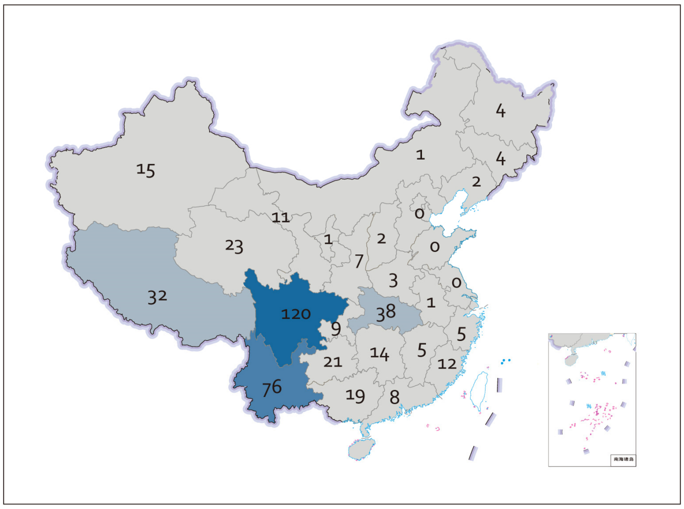
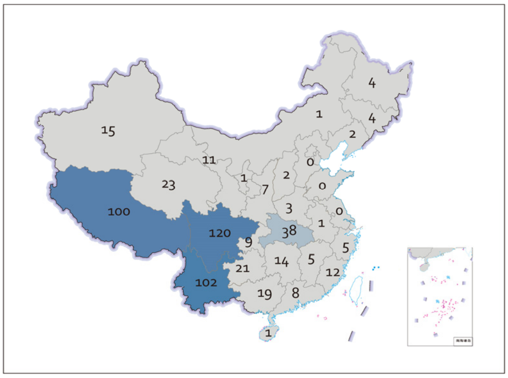


Table13-14 Hydropower development distribution in Sichuan, Yunnan, and Tibet(GW)

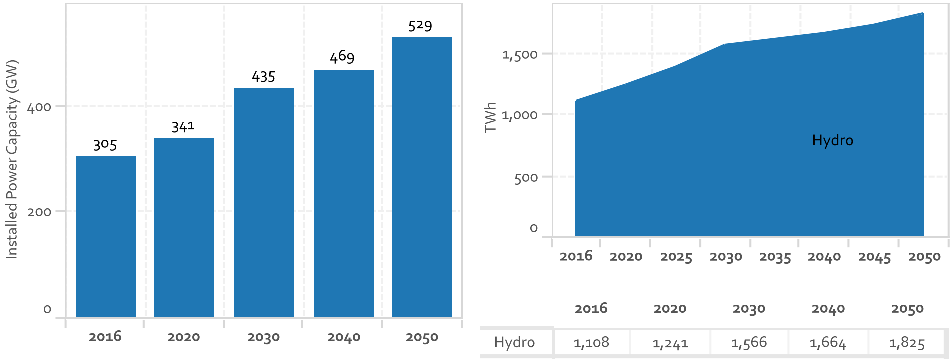
	Technically feasible resources	2020 capacity	2030 capacity	2050 capacity
Sichuan	146.9	78.6	120.0	120.0
Yunnan	117.3	64.9	75.7	101.9
Tibet	151.5	7.1	31.6	99.9
Total	**415.7**	**150.7**	**227.4**	**259.8**

Figure 13-36 China's hydropower development distribution in 2050 (GW)



Hydropower development

Figure 13-37 Installed capacity (left) and production from hydropower (right) in the scenarios.



	2016	2020	2030	2040	2050
Hydro	1,108	1,241	1,566	1,664	1,825

Short-term development

By 2020, total installed conventional hydropower capacity nationwide is expected to reach 341 GW, of which26 GW in the east region accounts for 7.6% of the national total. Basically, hydropower resources are fully utilized in this region, covering Beijing-Tianjin-Hebei, Liaoning, Shandong, Shanghai, Jiangsu and Guangdong where hydropower resource development shifts into deep-level exploitation; total development scale of the central region reaches 80 GW, accounting for 23% of the national total. The development level reaches 80% or higher in this region, covering Anhui, Jiangxi, Henan and Hubei where hydropower development shifts into deep-level exploitation; total development scale of the southwest region reaches 199 GW, accounting for 56% of the national total. The region's development level reaches 43%. Basically, hydropower resources in Guangxi, Chongqing and Guizhou are fully utilized. Sichuan, Yunnan and Qinghai still hold relatively large development potential. The Tibet Autonomous Region sees a relatively low development and utilization level and hence has the condition for large-scale development.

	2020
Total installed hydropower capacity (GW)	341
Development and utilization rate (%)	49%

Medium-term development

From 2021, the hydropower development focus is to gradually shift towards the upper reaches of the Jinsha, Lancang and Nu Rivers. By 2030, installed conventional hydropower capacity is expected to reach 434 GW. Under the below 2 degrees Celsius scenario, it will account for approx. 9.2% of total installed power generation capacity, whilst under the stated policy scenario, it will account for about 12%. The development level is expected to reach 62%. During 2021-2030, in total, 90 GW of hydropower capacity will be installed. This mainly includes 24.5 GW in Tibet, 41.4 GW in Sichuan and 10.8 GW in Yunnan.

	2030
Total installed hydropower capacity (GW)	434
Development and utilization rate (%)	62%

Long-term development

After 2030, the main focus of China's hydropower development will be moving into the main stream of the Yarlung Zangbo River located in southern Tibet and the Tibet Autonomous Region. Compared to other rivers, the development of the Yarlung Zangbo River poses more challenges. Hence, the developing plan should be made scientifically, in combination with the aid of technological innovation in hydropower engineering and power transmission engineering. Technically feasible hydropower resources in the lower reaches of the Yarlung Zangbo River amount to 69.6 GW, capable of generating approximately 347.4 billion kWh of electricity per year, equal to three times the electricity output of the Three Gorges Hydropower damn. About 2000-3000 km away from China's middle and eastern load centres, this place has the basic conditions for large-scale development and power transmission. By 2050, installed conventional hydropower capacity is expected to reach 529 GW. Under the Below 2 °C scenario, it will account for approx. 9% of total installed power generation capacity, whilst under the stated policy scenario, it will account for about 11%. The development level is expected to reach 76%.

	2050
Total installed hydropower capacity (GW)	5.29
Development and utilization rate (%)	76%

Hydropower transmission plan

In 2020, the scale of hydropower transmission is expected to reach 78 GW. Hydroelectricity generated in Sichuan and Tibet will be mainly transmitted to the central and east regions and hydroelectricity generated in Yunnan will be mainly transmitted to Guangdong and Guangxi.

Hydroelectricity generated by hydropower stations in the lower reaches of the Jinsha River (located in Yunnan and Sichuan) will be mainly transmitted to the central and east regions. Hydroelectricity transmitted from the lower reaches of the Jinsha River to the East China Power Grid will reach 13.6 and 22.6 GW, respectively, in 2015 and 2020; and that of the four central and east provinces will reach 18.4 GW in 2020.

Aside from meeting Sichuan's own load demands, the remaining hydroelectricity generated by hydropower stations on the Yalong, Dadu and Min Rivers within the territory of Sichuan Province may be transmitted to Chongqing and the central and east regions. The scale of grid-to-grid power transmission from the Sichuan Power Grid to power grids of the four central and east provinces will amount to 4 and 4 GW, respectively, in 2015 and 2020; and that to the East China Power Grid will reach 4 and 6 GW, respectively. In 2015, 7.2 GW of hydroelectricity was transmitted to the east region via DC bundling method from Jinping I and II, as well as Guandi, Hydropower Stations located in the lower reaches of the Yalong River. The same year also saw 4 GW of hydroelectricity transmitted to the four central and east provinces via DC method from Sichuan's Liangshanzhou region.

In 2030, except Tibet, hydropower resources in other regions across the country basically will be fully exploited. The planned scale of Tibetan hydroelectricity transmitted in 2030 is expected to reach 25.2 GW, of which 7.2 GW is to be transmitted to the Sichuan and Chongqing Power Grid, and 18 GW is to the East China Power Grid.

14 Fossil fuel energy outlook

Fossil fuels are the primary source of energy in China today. Coal is used extensively in both industries and power production while oil is dominating energy demand in the transport sector. In industries, fossil fuels make up 74% of energy consumption and 71% of power is generated from fossil fuels. In the transport sector 99% of energy is from fossil sources (primarily oil). The scenario analyses show that the use of fossil fuels will be drastically reduced in the future. This is the case in both scenarios, albeit at difference paces. Fossil energy will comprise 45% in the Stated Polices scenario and 25% of demand in the Below 2 °C scenario by 2050.

Figure 14-1 Fossil fuels by end-use sectors in the two scenarios (Mtce).

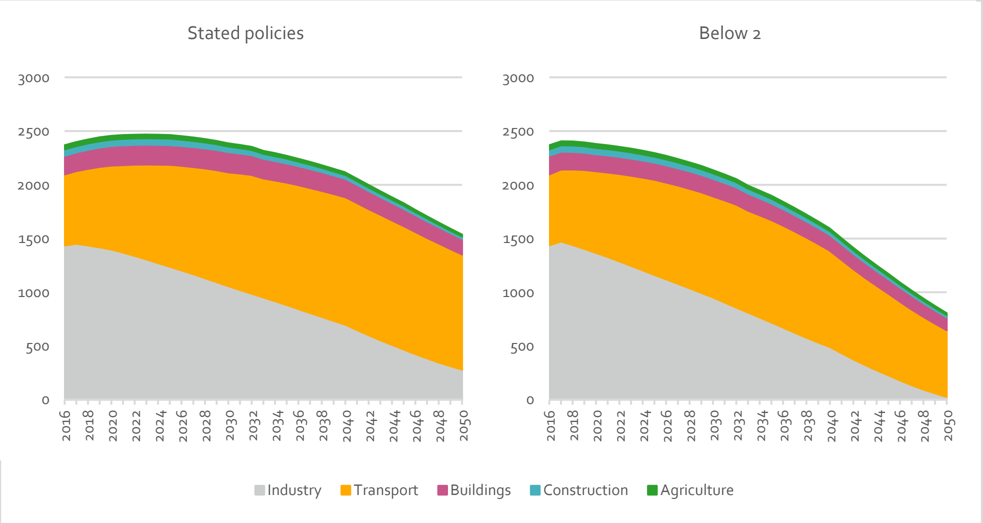
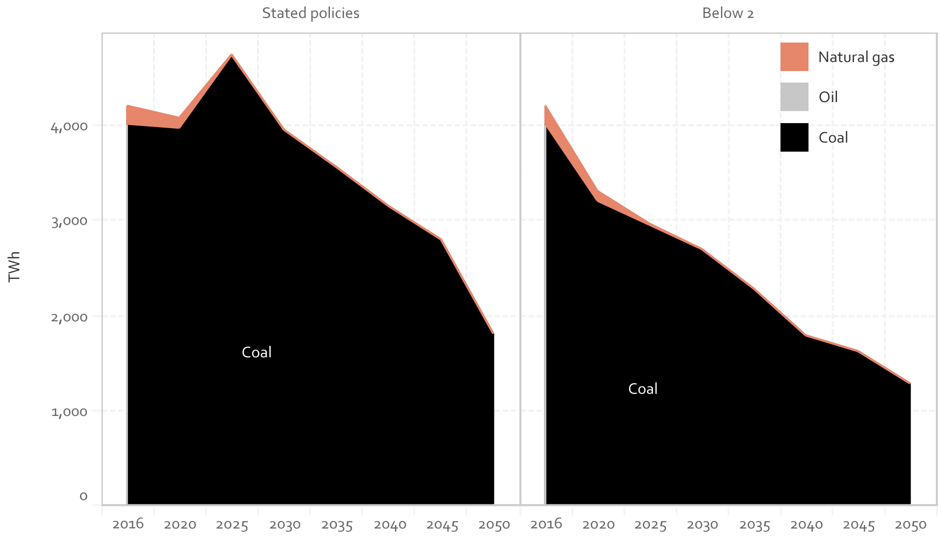


Figure 14-2 Fossil fuel power generation in the two scenarios.



	2016	2020	2030	2040	2050	2016	2020	2030	2040	2050
Grand Total	4,199	4,073	3,949	3,143	1,800	4,199	3,302	2,690	1,779	1,274
Natural gas	189	106	3	2	2	189	105	2	0	0
Oil	1					1				
Coal	4,009	3,967	3,946	3,141	1,799	4,009	3,196	2,688	1,779	1,274

For power generation, coal is currently by far the main fuel in China. Coal will not keep this position, but other fossil fuels will not take its place. Some natural gas is used in power generation while the use of oil in power generation is insignificant. The use of fossil fuels in China's primary energy supply has already peaked in the Below 2 °C scenario while it will peak in 2025 in the Stated Polices scenario. This is also true for fossil fuels in the power sector where fossil fuel generated power peaks at 4,742 TWh in 2025 in the Stated Polices scenario. The following sections, divided by fuel, analyse development of fossil fuel use in power and end-use sectors.

14.1 Coal outlook

Coal in the power sector

This section details the key assumptions and outlook for fossil fuel power in the short (2020), medium (2030) and long-term (2040-2050).

China's coal power situation

China's installed coal-fired capacity was 967 GW at the end of 2016, that is 7 GW above the assumed peak before 2020 in CREO2016. This primarily relates to an upward revision in the installed capacity by the end of 2015 given the CEC annual statistics, but also completed projects in 2016. During 2016 the Chinese government took several actions to cut overcapacity. Planned projects have been suspended and even projects under construction have been halted[56]. The assumption from CREO2016 that projects under construction would be finalised is no longer valid. This results in abandoning the minimum coal power development requirement until 2020 used in CREO2016. In April 2017, NEA issued a Notice of Issuing Early Warning of Risk on Planning and Construction of Coal-fired Power Plants for 2020 assessing financial and economic conditions to install coal power. This notice concluded that among the 32 provincial grid areas, 25 areas got a red-degree warning (highest level) and only two are green-listed. In April the NDRC issued recommendations on coal energy implementation[57] including a target to cut 150 million tons of coal production capacity in 2017 to reduce overcapacity.

Apart from cuts in overcapacity the Chinese government is preparing for a more flexible coal fleet. *The 13th FYP for Power Sector Development* states targets to retrofit 220 GW existing coal fired thermal power plants by 2020. The target is divided into 133 GW of CHP units and 86 GW condensing (power only) units primarily located in the three northern regions. The increased flexibility improves system value for coal generation as flexibility is valuable in a system with high shares of variable renewable energy. One of the main objective is to increase the load regulation capabilities as well as enhancing the flexibility using heat storage on the CHP units. Through enhancing the load regulation ability, the plan aims to obtain an additional 46 GW load capability[58].

Clean coal technology

The 13thFYP for power sector development stipulates average coal consumption of new coal-fired generating units to be less than 300 grams of standard coal per produced kWh by 2020. For existing coal-fired generating units the efficiency target is less than 310 grams of standard coal per kWh. Pollutant emission limits are set for coal power plants to be equal to those for natural gas, except for particulate matter where the standards are equal to the limit for other gas boilers. That is, 10 mg/m^3 for particular matter, 35 mg/m^3 for SO_2 and 50 mg/m^3 for NO_X. All regions must comply with the standards by 2020 at the latest. Eastern China must meet the standards by 2017 and the Central regions should aim to reach the standards by 2018[59].

The emission factor for coal power production used in the modelling is 90.65 kg CO2/GJ coal. If coal power would use the entire CO2 budget for the power and district heating sector in the Below 2 °C scenario it corresponds to 1.6 PWh produced electricity (using the 300 grams coal/kWh efficiency standard). This disregard all other CO2 emitting activities in power and district heating generation and it becomes evident that it is not possible for coal to play a significant part in a future low-carbon energy system.

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[56] (Beijixing dianliwang, 2017)

[57] (NDRC, 2017)

[58] (NDRC, 2016)

[59] (MEP, NDRC, and NEA, 2015)

Assumed efficiency rate for new coal plants is the same throughout the period. Larger plants have a higher efficiency rate while CHP plants are more efficient then condensing plants.

Table 14-1 Assumed efficiency in different plants.

Plant type	Efficiency
SC 660MW condensing plant	45.0%
USC 1000MW condensing plant	47.5%
350MW CHP plant	45.0%

The option to invest in CCS is available to the model. However, this option is not chosen which shows that with the current cost assumptions, proven technologies such as wind and solar are preferable to the system. The CO2 capture rate is assumed to be 85% for all coal CCS plants. Efficiency rates for coal plants with CCS are expected to increase while investment cost as well as operation and management costs fall over time.

Table 14-2 Assumptions related to CCS investments and corresponding plant without CCS.

Plant type	Efficiency	Investment cost factor	O&M cost factor
USC 1000MW coal plant **without** CCS	47.5%	1	1
USC 1000MW coal plant **with** CCS installed 2020-2029	36.0%	4.3	4.3
USC 1000MW coal plant **with** CCS installed 2030-2039	38.0%	3.5	3.7
USC 1000MW coal plant **with** CCS installed 2040-2050	39.0%	3.1	3.3

Thermal power plant flexibility options

In the modelling of the power and district heating market the model has been given the option to invest in both new flexible plants as well as investing in the retrofitting existing plants to become more flexible. Table 14-3 shows a simple overview of the most important plant options that exist in the model.

The retrofitted plants and the new flexible plant types are more flexible on several accounts that influence the model results. The flexible plants (both retrofitted and new flexible) have both higher maximum load, lower minimum load and faster ramping. For CHP plants an option is included to operate in partial bypass mode.

Table 14-3 Different coal-fired plant types with flexible option in the model

Power capacity (MW)	CHP	Condensing
300	Existing and retrofitted	
350	New standard units and new flexible units	N.A.
600	Existing and retrofitted	
660	N.A.	New standard units and new flexible units

Coal power generation and capacity development

In the Stated Policies scenario coal power will peak in 2025 generating 4,735 TWh by a total capacity of 983 GW while coal power has already peaked in the Below 2 °C scenario. This demonstrates that there is no need for new coal capacity, if China is to develop a low-carbon power system. As shown in Figure 14-3 coal phase-out of existing capacity starts with the small plants, these are assumed to be the oldest.

Figure 14-3 Phase out of existing coal capacity without reinvestments

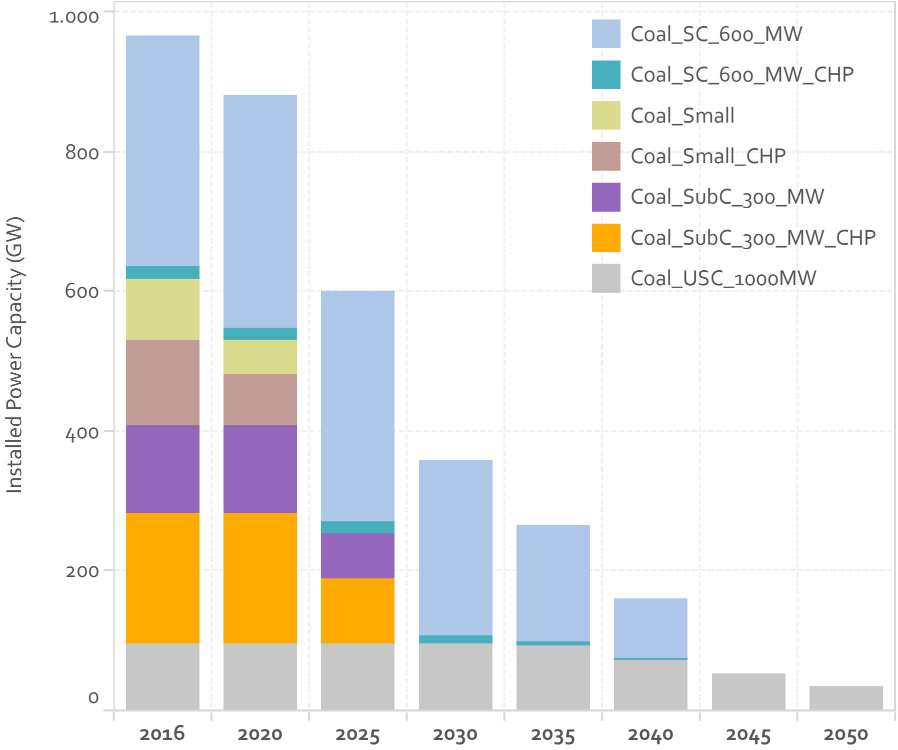
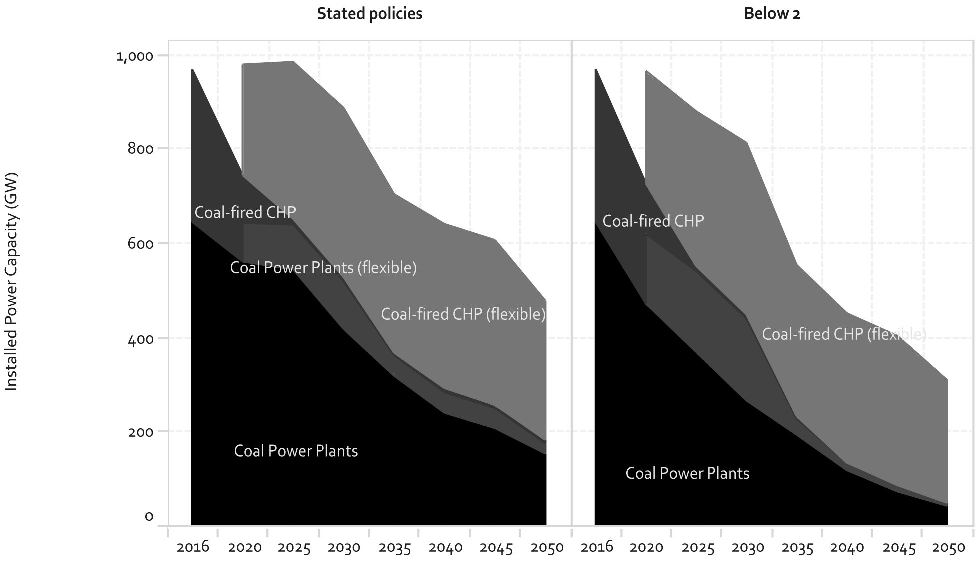
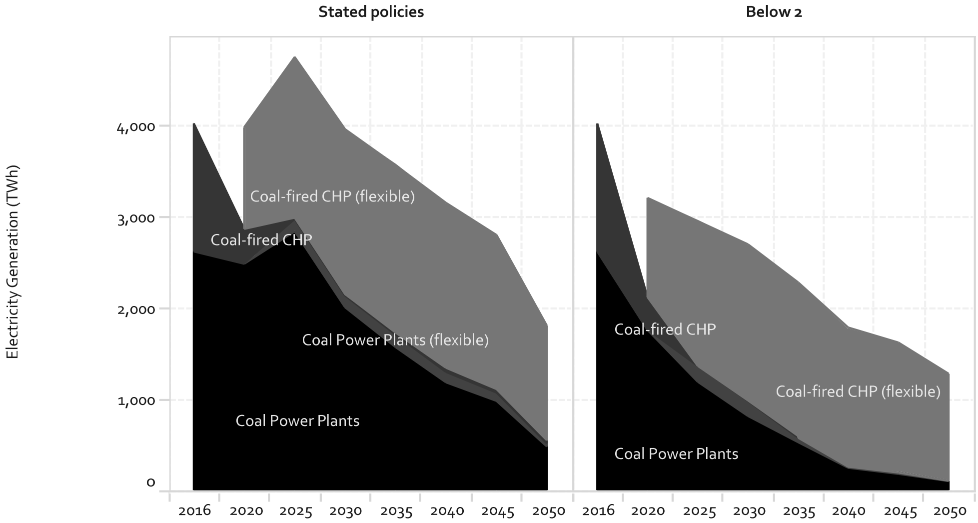


Figure 14-4 Coal power capacity (GW) development in the two scenarios.



	2016	2020	2030	2040	2050	2016	2020	2030	2040	2050
Grand Total	967	977	886	639	476	967	964	811	450	307
Coal Power Plants	644	560	417	239	152	644	471	265	117	41
Coal Power Plants (f..		34	34	4	11		62	62		
Coal-fired CHP	324	102	9	9	8	324	107	8	0	
Coal-fired CHP (flexi..		282	426	388	305		325	477	333	266

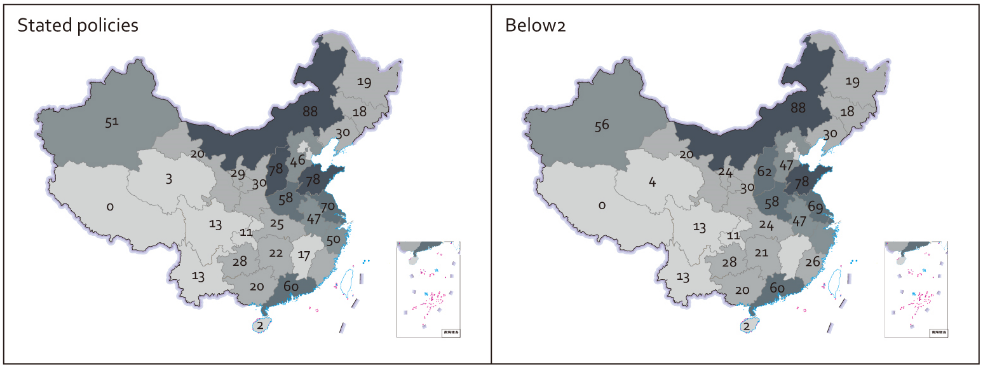
Figure 14-5 Coal power generation (TWh) development in the two scenarios.



	2016	2020	2030	2040	2050	2016	2020	2030	2040	2050
Grand Total	4,009	3,967	3,946	3,141	1,799	4,009	3,196	2,688	1,779	1,274
Coal Power Plants	2,610	2,474	2,000	1,179	478	2,610	1,753	812	246	100
Coal Power Plants (f..			11	20	26		2	13		
Coal-fired CHP	1,399	371	18	45	35	1,399	352	6		
Coal-fired CHP (flexi..		1,122	1,917	1,897	1,259		1,089	1,857	1,533	1,174

Short-term coal power development

Figure 14-5 Installed coal power capacity (GW) in the two scenarios in 2020.



In the short-term there is not much difference in absolute coal capacity in the two scenarios. The great difference is in the share of flexible power plants. Non-flexible coal power plants are more rapidly phased out in the Below 2 °C scenarios increasing the relative share of flexible CHP plant capacity.

There are significant investments in flexible coal power capacity in the short-term in both scenarios. In the Stated Policies scenario, a rapid development of retrofitted and new coal-fired CHP and to some degree retrofitted condensing (power-only) units can be observed. The cost of obtaining flexibility from thermal power plants is low enough to incentivize significant amounts already in 2020.

The far largest share of flexibility is by far obtained from CHP units, while condensing units play a lesser role. By 2020 around 70 % of all CHP units are flexible and by 2025 and forward almost all CHP plants are considered flexible. When observing the development of condensing units only around 13 % will be flexible by 2020. In the Below 2 °C scenario a rapid development of flexible capacity is also observed. For the CHP units the development is almost identical with the Stated Policies scenario. By 2020 around 69% of the installed capacity is flexible and from 2025 and forward basically all CHP capacity will be flexible.

Compared to the target of 220 GW retrofitted coal-fired capacity by 2020 (86 GW condensing and 133 GW CHP) the model results show a total of 316 GW flexible capacity where 82 GW is retrofitted condensing units; 174 GW is retrofitted CHP plant capacity. Apart from this 61 GW new flexible CHP capacity is added (while 51 GW existing small size CHP capacity is retired).

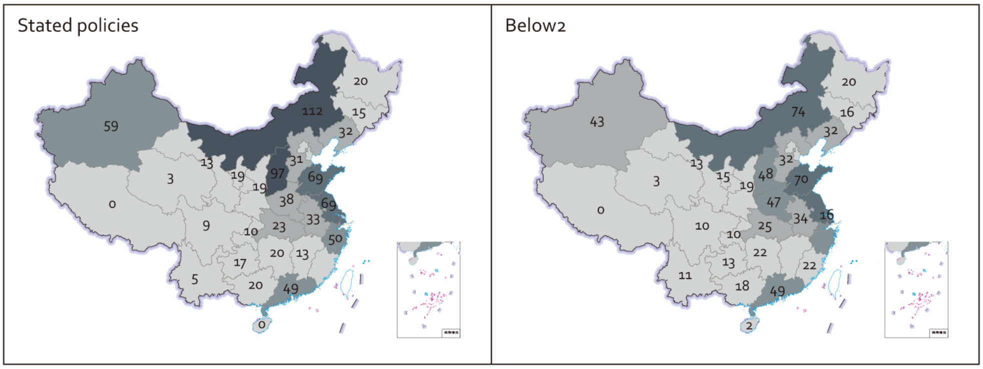
Provinces with the highest curtailment rates have the most retrofitted CHP in 2020. While 70% of all CHP capacity on a national level (Stated Policies scenario) is retrofitted by 2020, a higher degree of retrofitted or new flexible CHP plants can be observed in the provinces with the highest degree of curtailment of wind and solar power in 2016. This is clear in Table 14-4as these lie above national average shares of retrofitted CHP.

Table 14-4 Development of retrofitted CHP or new flexible CHP in provinces with high curtailment

Stated Policies scenario	Wind curtailment 2016	Solar curtailment 2016	Share of CHP retrofitted in 2020
National	17%	10%	70%
Gansu	43%	30%	89%
Xinjiang	38%	32%	89%
Jilin	30%	0%	75%
Inner Mongolia	21%	7%	79%
Heilongjiang	19%	0%	70%

Medium-term coal power development

Figure 14-6 Installed coal power capacity (GW) in the two scenarios in 2030.



By 2030 there are significant differences in provincial capacity between the two scenarios. In Xinjiang, Inner Mongolia, and Shanxi coal capacity is reduced in the Below 2 °C scenario, compared to the Stated Policies scenario. Most flexible thermal power development happens on the short and mid-term from 2016 to 2030 in both scenarios. In 2030 there is a peak of flexible coal CHP capacity in both scenarios, emphasizing that coal plant flexibility may be an important transitional measure. Non-flexible coal CHP is almost completely phased out and other coal fired power and district heating generation has been declining for many years.

Table 14-5 Development of flexible thermal in the Stated Policies scenario

Technology (group)	2016	2020	2025	2030	2035	2040	2045	2050
Coal-fired CHP (flexible) 1		234	333	359	336	348	349	295
Coal-fired CHP	324	102	12	9	6	9	7	8
Flexible share of CHP plants		70%	97%	98%	98%	98%	98%	98%
Coal Power Plants (flexible) 2		82	95	101	43	44	42	21
Coal Power Plants	644	560	543	417	317	239	206	152
Flexible share of condensing plants		13%	15%	19%	12%	15%	17%	12%
CHP share of total flexible plants		74%	78%	78%	89%	89%	89%	93%
1) New flexible 350 MW CHP plants and retrofitted 300 MW and 600 MW units								
2) Retrofitted 300 MW and 600 MW condensing (power only) units								

In the Stated Policies scenario 19% of condensing units are flexible while almost all CHP coal plants are flexible by 2030. The development of flexibility on condensing mode plants in the Below 2 °C scenario results in a higher degree of flexible condensing capacity compared to the Stated Policies scenario. The higher share of VRE in the Below 2 °C scenario requires more system flexibility and consequently a higher degree of the condensing units are likely being retrofitted to become more flexible in the scenario compared against the Stated Policies scenario. This is true for the short and mid-term where 24-40 % of all condensing capacity is flexible in the Below 2 °C scenario.

Just as in the Stated Policies scenario, in the below2 scenario most of the flexible capacity is generally obtained on CHP plants installed or retrofitted between 2016 and 2030.

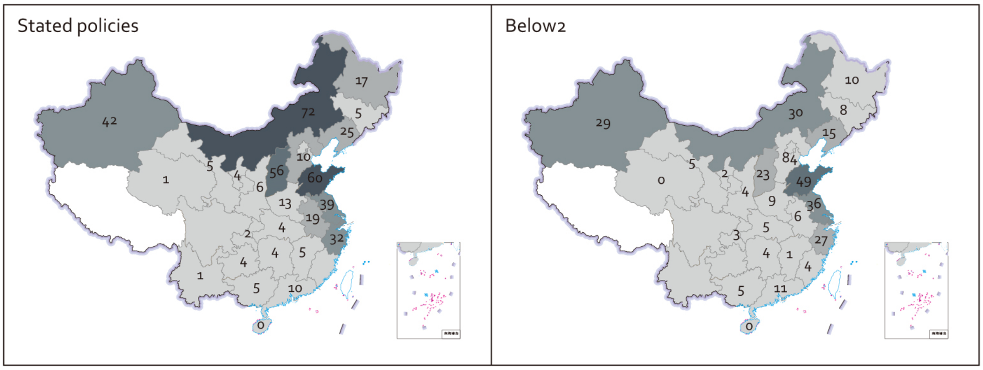
Table 14-6 Development of flexible thermal units in China under the Below 2 °C scenario

Technology (group)	2016	2020	2025	2030	2035	2040	2045	2050
Coal-fired CHP (flexible) 1		239	328	364	321	317	317	260
Coal-fired CHP	324	107	11	8	5	0	0	0
Flexible share of CHP plants		69%	97%	98%	98%	100%	100%	100%
Coal Power Plants (flexible) 2		148	171	174	34	16	13	6
Coal Power Plants	644	471	368	265	192	117	72	41
Flexible share of condensing plants		24%	32%	40%	15%	12%	16%	14%
CHP share of total flexible plants		62%	66%	68%	90%	95%	96%	98%
1) New flexible 350 MW CHP plants and retrofitted 300 MW and 600 MW units								
2) Retrofitted 300 MW and 600 MW condensing (power only) units								

Another key observation is the rapid reduction of condensing units in both scenarios, while the generation capacity of CHP plants maintains relatively stable. This development is to a large extent similar to that seen in Denmark over the last decades, where basically only CHP plants are left in the market due to their much higher total energy efficiency and the opportunity to cover costs on both power and heat markets.

Long-term coal power capacity development

Figure 14-7 Installed coal power capacity (GW) in the two scenarios in 2050.



Stated policies

Below2

In the long-term total coal power capacity has been reduced from 4,009 GW in 2016 to 1,799 in the Stated Policies scenario and 1,274 GW in the Below 2 °C scenario. Coal makes up 19% of primary energy supply in the Stated Policies scenario and 13% in the Below 2 °C scenario, down from 65% in 2016.

The majority of coal plants are CHP plants which are operated efficiently and flexibly. From 2035 and forward flexibility from new flexible CHP units become the dominant source of CHP plant flexibility. The amount for flexible capacity decreases in absolute terms from 2030 as other sources of flexibility (EVs, batteries, pumped storage etc.) starts to deliver flexibility to the system.

Table 14-7 Source of flexible CHP capacity development under both scenarios

Share of flexible CHP capacity	**Stated Policies scenario**						
	2020	2025	2030	2035	2040	2045	2050
Retrofitted existing CHP	74%	55%	51%	3%	0%	0%	0%
New flexible CHP plants	26%	45%	49%	97%	100%	100%	100%
Share of flexible CHP capacity	**Below 2 °C scenario**						
	2020	2025	2030	2035	2040	2045	2050
Retrofitted existing CHP	71%	54%	49%	3%	1%	1%	1%
New flexible CHP plants	29%	46%	51%	97%	99%	99%	99%

In the Stated Policies scenario there is an incline of full-load hours (FLH) in the short to medium-term and a peak in 2035, while in the coal FLH decline in the Below 2 °C scenario until they increase in by 2035.

Figure 14-8 Coal power full load hours development in the two scenarios.

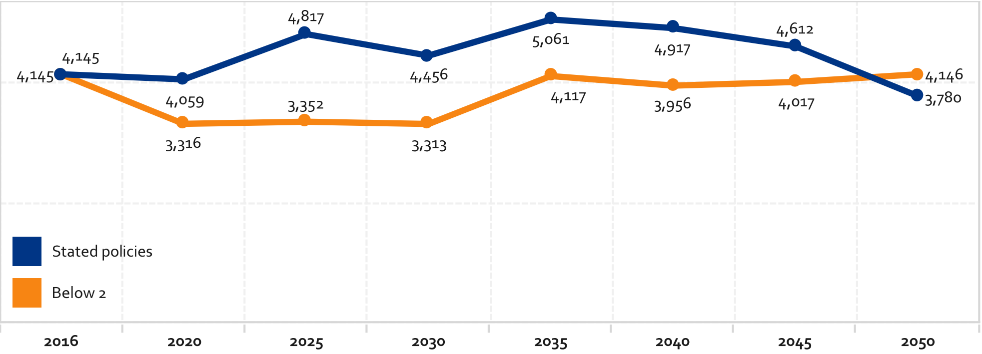
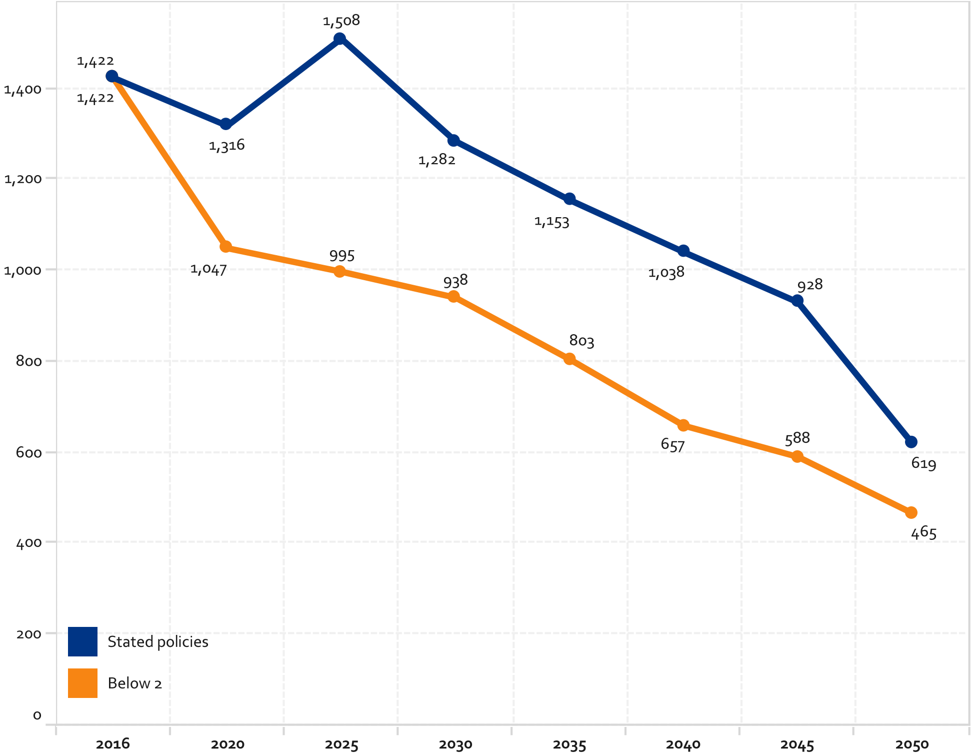


Figure 14-9 Coal use (Mtce) in the power and district heating sectors in the two scenarios.



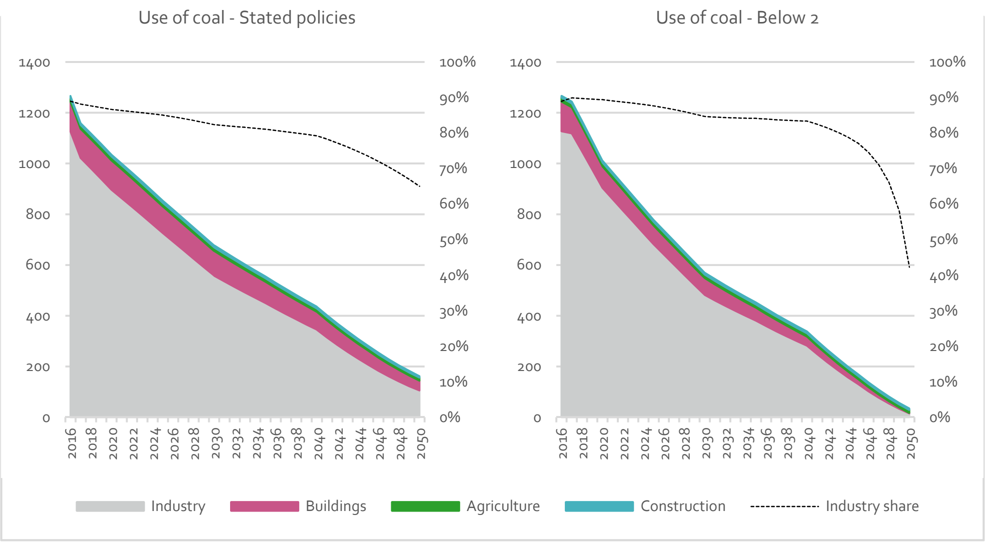
In the Stated Policies scenario coal use is reduced before the peak is reached in 2025. Hereafter coal use is steadily reduced at the same pace as in the Below 2 °C scenario until

2045 where we see more drastic reductions until 2050. In the Below 2 °C scenario coal use declines rapidly in the short-term due to carbon constraints, followed by a steady decline to 2050. The decisive initial actions in the Below 2 °C scenario allows for more moderate reductions in the end of the period. Coal power is reduced from covering 67% in 2016 to 28% of produced power in 2040 and 14% of power consumption in 2050 in the Stated Policies scenario. For the Below 2 °C scenario the coal power makes up 14% of generated power in 2040 and 8% in 2050.

Coal in end-use sectors

For direct use in the end-use sectors, coal is today predominantly used in industry, but also in buildings, agriculture, and construction.

Figure 14-10 Use of coal in end-use sectors in the two scenarios.



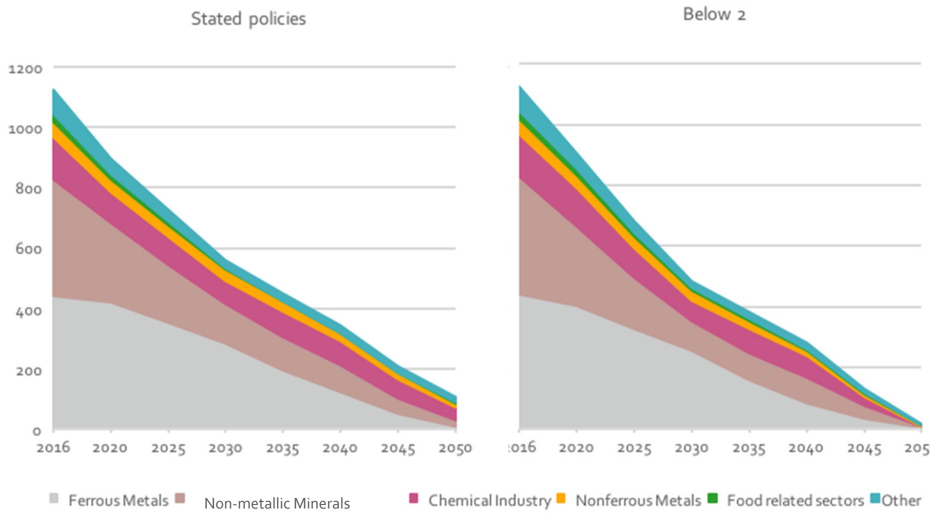
Until 2050 the overall coal use in end-use sectors declines steadily in both scenarios, yet at a faster pace in the Below 2 °C scenario. The industrial share of coal use is reactively stable throughout the period with a decrease in very end. As coal use in agriculture and construction sectors remain stable in absolute terms, these make up a relatively larger share in the end of the period. Coal use in buildings is reduced in both scenarios though at a much faster pace in the Below 2 °C scenarios.

Coal use in industry

Industry accounted for 89% of direct end-use coal consumption in 2016. As energy use in industrial processes get more efficient and the economy is shifting away from heavy industry, the use of coal in industry is reduced, both in absolute and in relative terms.

Coal use goes from 1,266 Mtce in 2016 to 162 Mtce in the Stated Policies scenario and 35 Mtce in the Below 2 °C scenario. These extensive reductions are due to significant reductions of coal use in all heavy industries where coal is replaced with natural gas, biomass, and electricity.

Figure 14-11 Use of coal in different industrial sectors in the two scenarios.

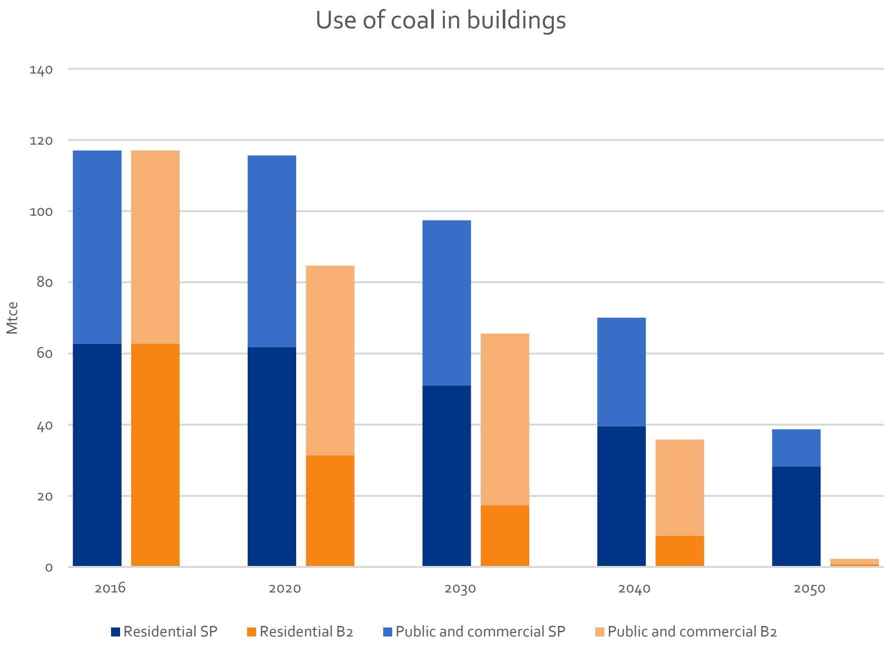


Coal use in the non-metallic minerals sector is substantially reduced in the short term. The ferrous metals sector (including the steel sector) is a particularly important sector for coal reductions in the medium to long-term where electrification of this industry extensively reduces coal consumption. The overall share of direct coal use attributable to industry declines from 68% in 2016 to 10% in the Stated Policies scenario and 1% in the Below 2 °C scenario in 2050.

Coal use in buildings

Total coal use in buildings is lower in Below 2 °C scenario as there is more substitution of coal with biomass and solar in the Below 2 °C scenario. The ratio between residential and public and commercial buildings is currently about 50/50, this develops in opposite directions in the two scenarios with a higher relative use in residential buildings in the Stated Policies scenario and a higher use in public and commercial buildings in the Below 2 °C scenario. This is as most of the improvements and changes in fuel use is performed in residential buildings. Coal use in public and commercial buildings is the same in both scenarios until 2040. In the very end of the period reductions of coal use are performed in the public and commercial buildings sector in both scenarios, but these are much more extensive in the Below 2 °C scenario.

Figure 14-12 Coal use in buildings in the Stated Policies scenario (SP) and the Below 2 °C scenario (B2)

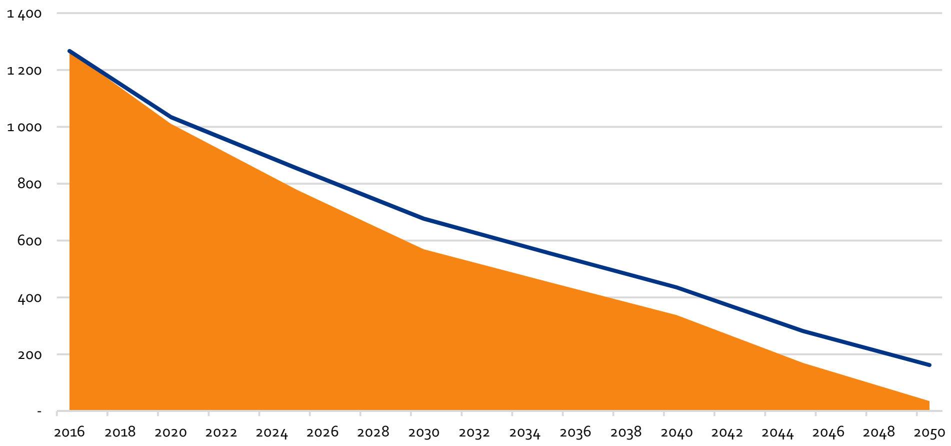


Other coal use

In the agriculture and construction sectors absolute levels of coal use remain pretty much the same in both scenarios as the total energy demand for these sectors is marginally reduced while the fuel composition remains the same.

Total coal energy development

Figure 14-13 Coal in total final energy demand (Mtce) in the Stated Policies (blue line) and the Below 2 °C scenario (orange area).



Presently about half of coal is used in the power sector while the other half is used in the industry. In both scenarios coal is largely substituted by other sources. Most use in end-use sectors is substituted and in the power sector coal will play a small yet active role. The substitution is much more extensive in the Below 2 °C scenario where coal in total energy demand is about half of the level in the Stated Policies scenario.

Challenges for the coal dependent provinces

The drastic reduction of the use of coal in both scenarios is beneficial for the Chinese society and will significantly reduce the emission of CO_2 and improve the air quality. However, for provinces which economy is heavily depending on coal mining or income from coal power production, the reduction could have severe impact on the local economy and the jobs in the coal sector. Experiences from Germany, Great Britain and USA show that the negative local consequences should be addressed with special measures and initiatives to change from the dependency of the old industry to new emerging industries, creating new momentum and job opportunities. The experiences also show that this is a difficult and long journey, and the Chinese coal-dependent provinces should prepare coal transition plans now.

Coal transition in Germany

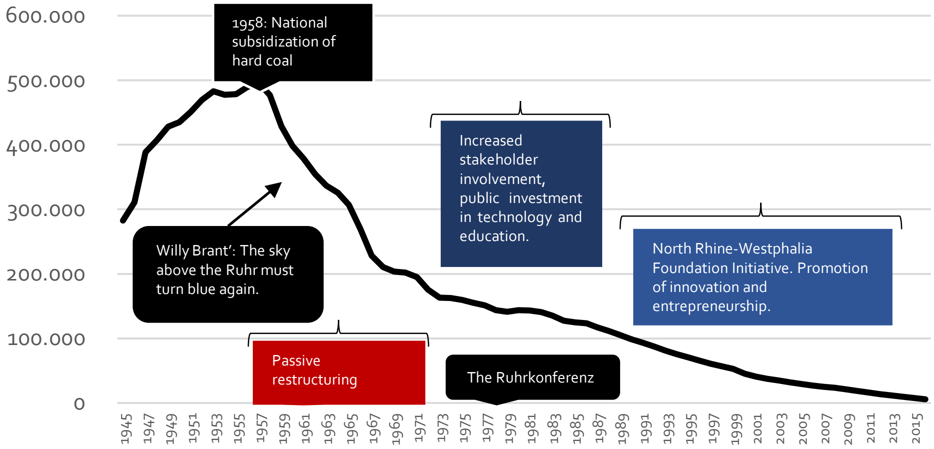
The Ruhr Valley is a part of the North Rhine-Westphalia State in Germany. Through the 19th century the region experienced growth, urbanization and development through booming coal and steel industries. The Ruhr Valley population grew from 400.000 in 1850 to a peak of 5.67 million in 1961.

By the 1950s coal, steel, and related industries employed 70 percent of the labour force. The region had a monolithic coal based economic structure. Cheaper coal from outside the region and increasing use of oil, led to mine closures. By the 1970s the steel industry faced the same economic pressure as steel was cheaper on the global market. In addition to the economic challenges, the environment had suffered from the rapid industrial development and urbanization.

Germany subsidized coal to ensure national energy security and to stall the impact of unemployment from decreased production and mine closures. From the late 1950s to mid-1970s the policy measures were from national and state level who responded as to temporary demand trends instead of acknowledging the structural crisis and need for economic diversification.

From the late 1970s to the unification, local policy makers took a bottom up approach through the Ruhrkonferenz, together with local stakeholders. Through the 1980s this led to active structural change by creating technology and innovation centres and supporting SMEs. The infrastructural development fostered inward investment and the shifted focus to technological advancement in North Rhine-Westphalia continued through 1990 and 2000s. The region now promotes innovation and entrepreneurship and the last coal mine is set to close in 2018.

Figure 14-14 Coal industry employees in the Ruhr valley



14.2 Natural gas outlook

Natural gas in the power sector

This section details the key assumptions and outlook for natural gas power in the short (2020), medium (2030) and long-term (2040-2050).

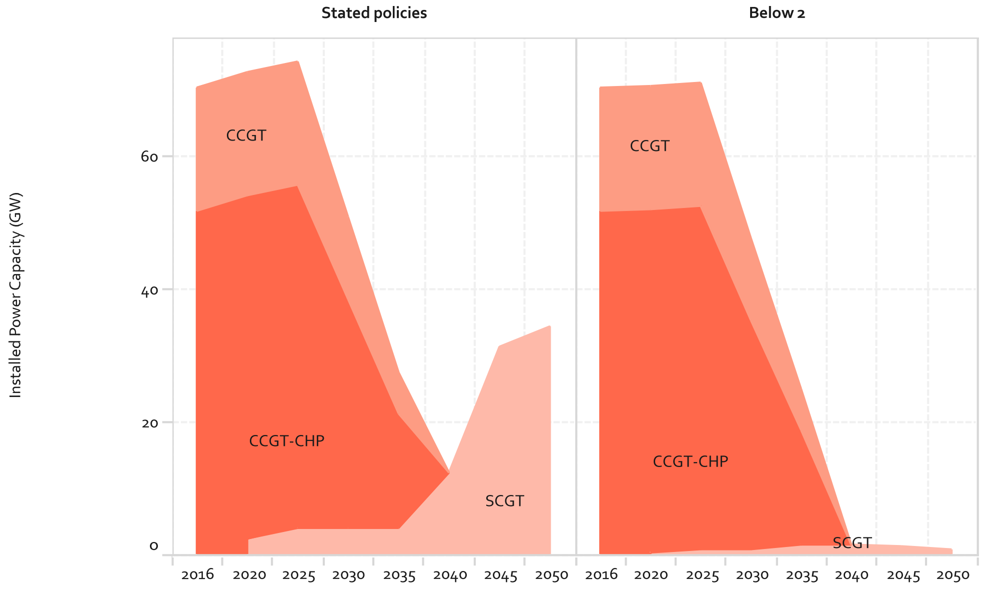
China's natural gas power situation

The 13thFYP sets targets for natural gas power development. Natural gas should cover 10% of energy consumption and 50 GW of natural gas power capacity should be installed during the 13thFYP period. By 2020 natural gas power capacity is expected to reach 110 GW including 15 GW of CCHP (combined cooling heating and power) plants.

The modelling results differ from these targets and the conception that natural gas will play a dominant role in China's power transition. Expanded use of natural gas power is motivated by assuring low-carbon flexible generation to regulate peak load. The results from the modelling shows that these services can provided in other ways. Natural gas is costly and renewable energy prices are coming down. This while increased flexibility in coal generation and storage provide means to balance fluctuating generation. All diminishing the need for natural gas power.

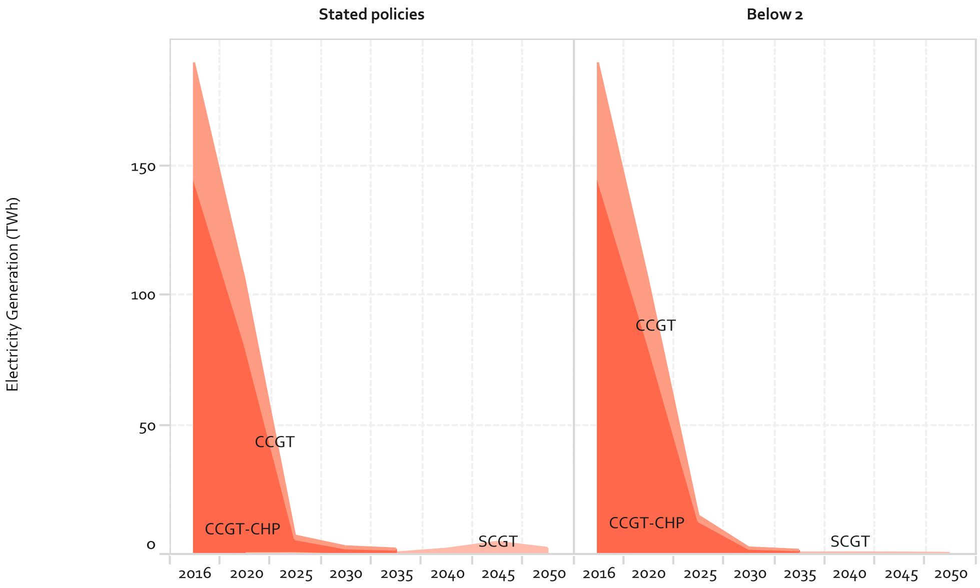
Capacity and generation development

Figure 14-15 Natural gas capacity (GW) development in the two scenarios.



	2016	2020	2030	2040	2050	2016	2020	2030	2040	2050
Grand Total	70	72	51	12	34	70	70	47	1	1
CCGT	19	19	12	0		19	19	12	0	
CCGT-CHP	52	52	34	0		52	52	34	0	
SCGT		2	4	12	34		0	1	1	1

Figure 14-16 Natural gas generation (TWh) development in the two scenarios.

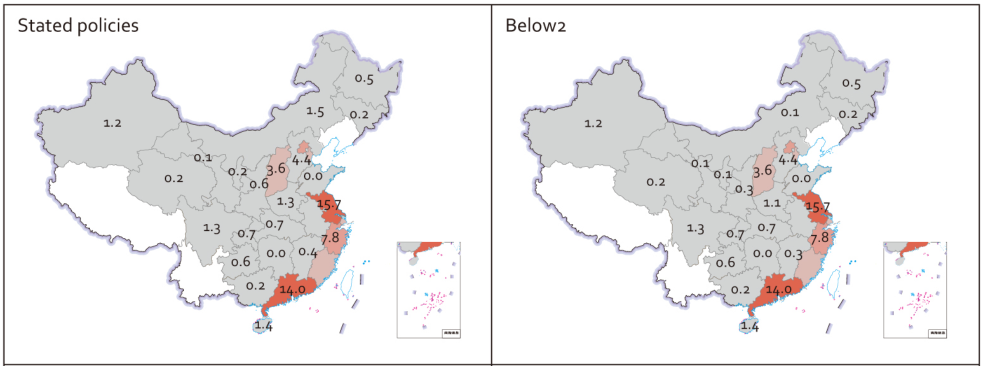


	2016	2020	2030	2040	2050	2016	2020	2030	2040	2050
Grand Total	189	106	3	2	2	189	105	2	0	0
CCGT	45	25	1			45	25	1		
CCGT-CHP	144	80	2			144	80	2		
SCGT		1	0	2	2		0	0	0	0

Short-term development

By 2020 there will be 72 GW installed natural gas power capacity in the Stated Policies scenario, compared to 70 GW in the Below 2 °C scenario. The vast majority is CHP plants. Natural gas contributes less and less to power generation as costs are too high for considerable utilisation. The total capacity by 2020 is substantially lower than the 110 GW capacity target stated in the 13thFYP. The installed natural gas capacity is practically the same as the current situation, as merely small amounts of SCGT have been added in the Stated Policies scenario. Most capacity is located on the east coast close to the load centres.

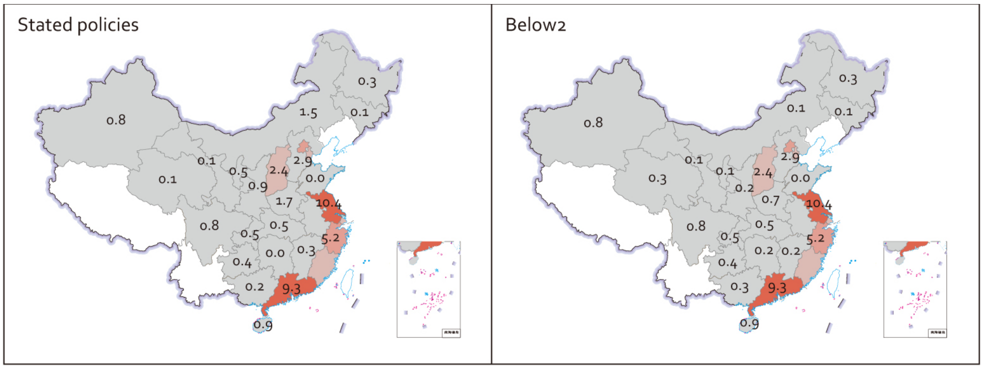
Figure 14-17 Installed natural gas capacity (GW) by province in 2020.



Medium-term development

By 2030 some existing natural gas plants get retired. By now natural gas is only used to a very small extent in the power and district heating sector.

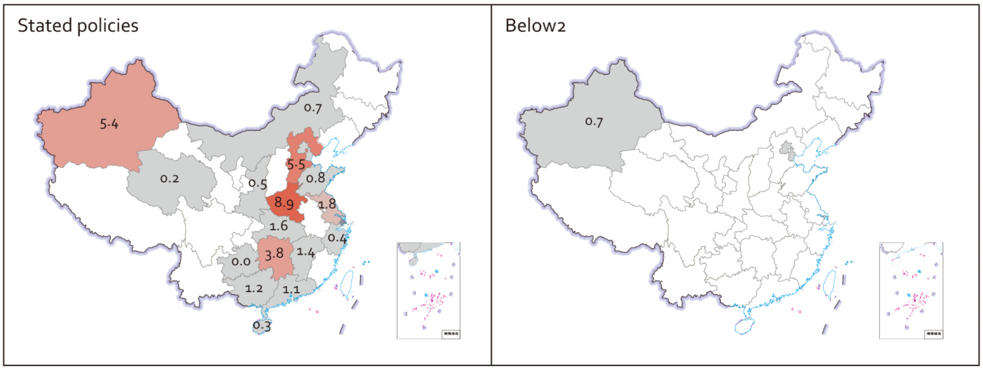
Figure 14-18 Installed natural gas capacity (GW) by province in 2030.



Long-term development

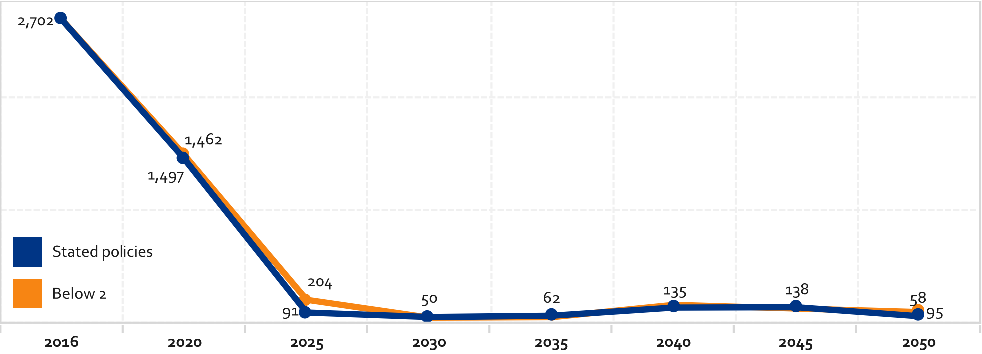
By 2040 and 2050 all CCGT generating capacity is retired. There are exceeding investments in SCGT capacity in the Stated Policies scenario and minimal investments in SCGT in the Below 2 °C scenario. This results in a 2050 picture where all installed natural gas capacity is SCGT. In the Stated Policies scenario this is located in north and central provinces.

Figure 14-19 Installed natural gas capacity (GW) in 2050 in the two scenarios.



The development of natural gas utilisation is a result of the associated CO2 emissions and high cost from natural gas power generation. SCGT generators is rarely used and only need a few full load hours to be profitable. Both costs and CO2 emissions associated with natural gas power generation are high, resulting in stranding natural gas assets.

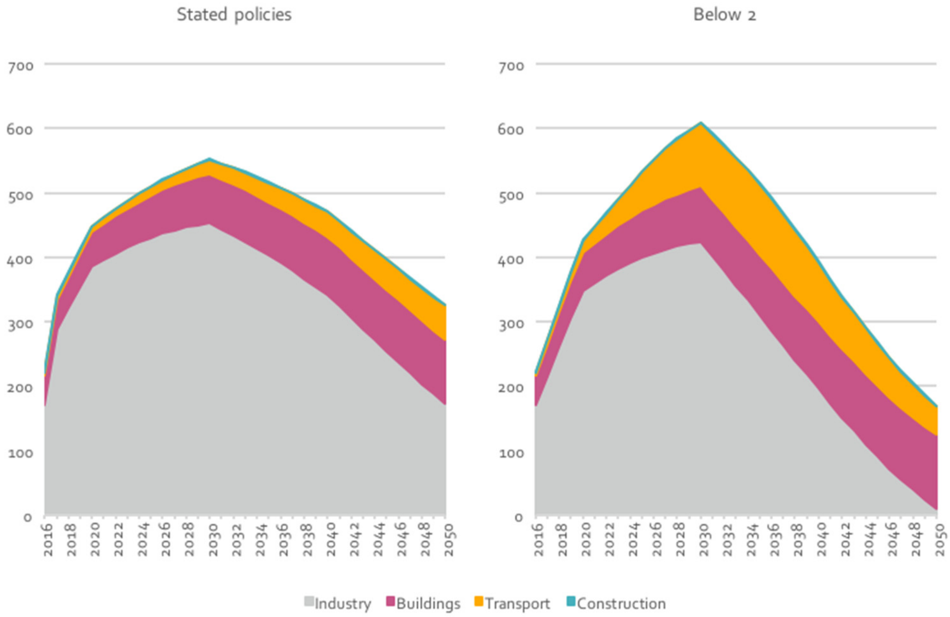
Figure 14-20 Natural gas full load hours development in the two scenarios.



Natural gas in end-use sectors

Most natural gas is currently used in in the industrial sector. This will expand in the short to medium-term in both scenarios while the use of natural gas in the transport sector increased in the Below 2 °C scenario. In 2030 natural gas in end-use sectors reaches its peak in both scenarios. From this peak to 2050 the use of natural gas is drastically reduced in the Below 2 °C scenario as the carbon emission budget pushing for increased electrification. By 2050, extensive electrification of the industry sector in the Below 2 °C scenario has made buildings the sector using the most natural gas, while the industry still uses the most natural gas in the Stated Policies scenario.

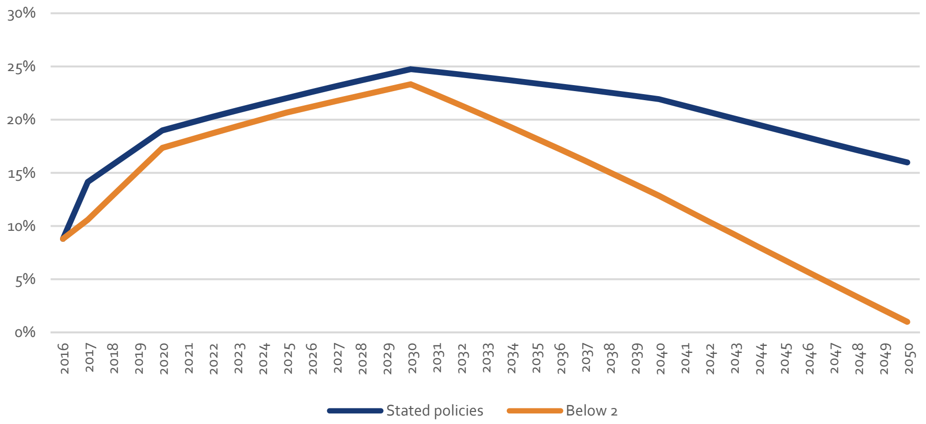
Figure 14-21 Direct use of natural gas in end-use sectors (Mtce).



Natural gas in industry

Use of natural gas in industry follows a similar trend in both scenarios up until the peak in 2030. In the short to medium-term natural gas is primarily replacing use of coal in both scenarios. From 2030 to 2050 natural gas is rapidly phased out and replaced by electricity, this development is seen in both scenarios, yet at a faster pace in the Below 2 °C scenario. In 2050 natural gas makes up 16% of industrial energy consumption in the Stated Policies scenario, while this is 1% in the Below 2 °C scenario.

Figure 14-22 Natural gas use in industry in the two scenarios.



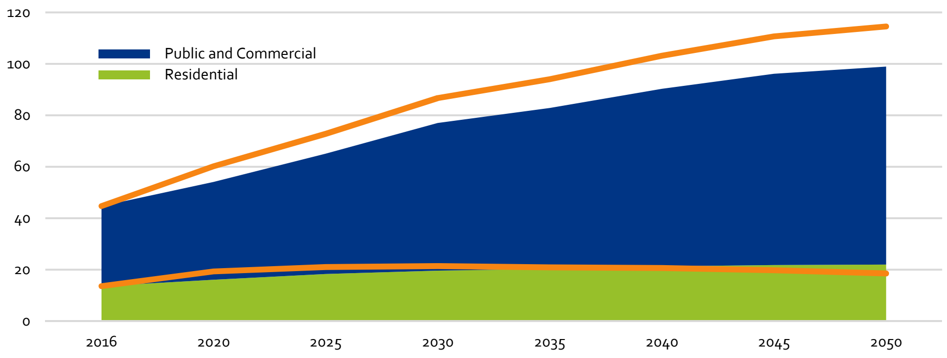
Natural gas in transport

In the Below 2 °C scenario there is a rapid expansion of use of natural gas in the medium-term as a low emitting fuel displacing oil in the transport sector.

Natural gas in buildings

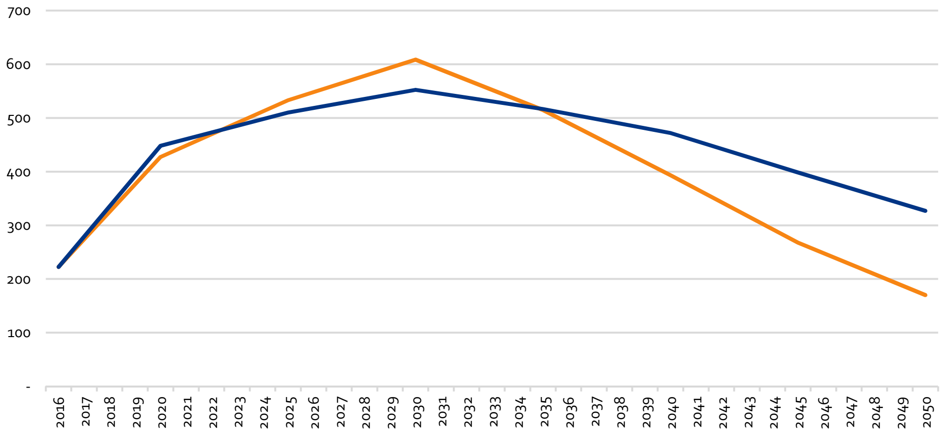
The use of natural gas in buildings expands over time. The development is similar in the two scenarios although it is used at a higher extent in the Below 2 °C scenario. The difference stems from an increased use of natural gas in public and commercial buildings. The use of natural gas in residential buildings is essentially the same in the two scenarios. Comparing the Below 2 °C scenario to the Stated Policies scenario there is a slight increase in use of natural gas in residential buildings the short-term and a slight decrease in the long term.

Figure14-23 Natural gas used in buildings (Mtce) in the Stated Policies scenario (stacked areas) compared to the Below 2 °C scenario (orange lines).



Total natural gas energy development

Figure14-24 Natural gas in total final energy demand in the stated policies (blue) and the below 2 (orange).



Use of natural gas is increases in both scenarios. In 2020 natural gas covers 13% of total energy demand in the Stated Policies scenario and 12% in the Below 2 °C scenario, meeting the 10% minimum target stated in the 13thFYP. At its peak in 2030 natural gas covers 14% of demand the Stated Policies scenario and 16% in the Below 2 °C scenario. Natural gas is used as an intermediate fuel to displace high emitting oil in the transport sector, specifically in the Below 2 °C scenario. Here, the use of natural gas is to a large extent replaced by electricity in the long term. The greatest difference between the scenarios is the direct use of natural gas in industry, in the Below 2 °C scenario electrification of the industry significantly reduces the demand for natural gas in industry after the natural gas peak in 2030, while natural still used quite extensively in industry.

14.3 Oil outlook

The role of oil in the power sector is insignificant which is why this section exclusively describes development of oil use in the end-use sectors.

Oil in end-use sectors

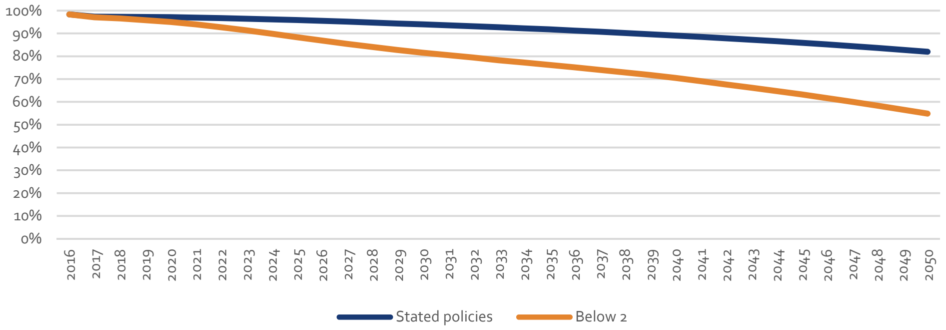
Oil is most extensively used in the transport sector. Apart from this oil products are also used in the industry, construction sector, agriculture, and in buildings. The use of oil in industry is gradually faded out as it is replaced by other fuels. The direct use of oil products in end-use sectors peaks around 2040 in the Stated Policies scenario and in 2025 in the Below 2 °C scenario.

Figure14-25: Direct use of oil in end-use sectors in both scenarios (Mtce).

Oil in transport

As the demand for transport services is expected to increase the total use of oil in transport will increase in the Stated Policies scenario with a peak around 2040, while it peaks around a decade earlier in the Below 2 °C scenario. China's extensive EV policies will reduce the demand for oil products in the transport sector in the long-term. This is true for both scenarios however the development in the Below 2 °C scenario is more determined.

Figure 14-26: Share of oil used in transport in the two scenarios.



Oil in industry

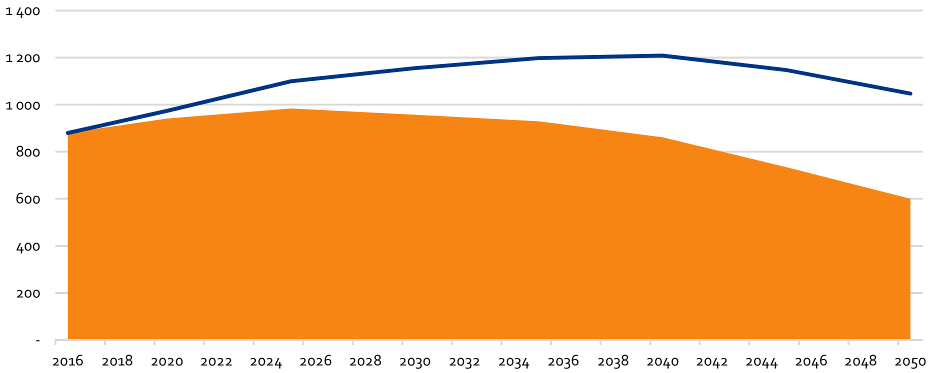
Oil use in industrial sectors are practically the same in the two scenarios. The chemical sector is the main user of oil products followed by non-metallic mineral products which uses about half of the amount used in the chemical sector. There is a steady decline of oil use throughout the period and the relative share between sectors remain pretty much the same.

Oil in other end-use sectors

Oil is used to a very small extent as direct use in agriculture, construction, and building sectors. The use of oil is gradually reduced in all these sectors over time in both scenarios.

Total oil energy development

Figure14-27 Oil in total final energy demand (Mtce) in the Stated Policies (blue line) and the Below 2 °C scenario (orange area).



Total oil demand peaks in 2040 in the Stated Policies scenario and in 2025 in the Below 2 °C scenario. In the Below 2 °C scenario there are substantial reductions in oil use in the long term. This will not only bring extensive environmental benefits, but also reduce potential need for oil imports and thus increase self-sufficiency. The gap in Figure14-27 illustrates the difference in oil use in the two scenarios. By 2050 the oil demand in the Below 2 °C scenarios is approximately half of that in the Stated Policies scenario. Despite electrification of the transport sector in the Stated Policies scenario is the total demand for oil products higher in 2050 compared to 2016. This is not the case in the Below 2 °C scenario where even more extensive electrification of the transport sector as well as reduced oil use in other sectors make it possible to reduce absolute levels of oil demand.

14.4 Conclusion

The total use of fossil fuels will be reduced in the long term. Coal demand is already on a steady decline in both scenarios. This is both a result of coal being replaced with other fuels and a result of China moving away from heavy industries and investing greatly in improving energy efficiency in the remaining heavy industry. Natural gas will be used as an intermediate fuel in the industrial and transport sectors, before it is replaced with electricity. Growing demand for transport services will increase oil demand followed by reductions in the long term.

In the power sector coal will be used more flexibly and the use of natural gas will be significantly reduced. Enhanced thermal power plant flexibility can play a key role in improving China's power system flexibility particularly in the short and medium-term (2020-2030). The model results show that the main driver behind the enhanced flexibility of thermal power plants will be through making the CHP plants more flexible and only to a much less degree making the condensing plants more flexible. In the short-term flexible CHP plants are a widespread source of flexibility in the power system on a national level. Provinces with high curtailment levels invest even heavier in more flexible CHP plants, as flexible CHP can be used as a mean to reduce curtailment of wind and solar power. After around 2030 other flexibility is obtained in the system for example from EV, batteries and pump hydro. Specifically, flexibility from condensing plants is only a marginal contributor to the system flexibility.

References for Part 2 (chapters 6-14)

Beijixing dianliwang, 2017. NEA issued 13 provinces and cities to shut down construction of new coal power. [Online] Available at: http://news.bjx.com.cn/html/20170116/803648.shtml

Bross, U. & Walter, G.H. 2000. Socio-economic Analysis of North-Rhine Westphalia. Karlsruhe: Fraunnhofer Institute for Systems and Innovation Research

Bruckmann, P., Pfeffer, U., & Hoffmann, V. 2014. 50 years of air quality control in Northwestern Germany – How the blue skies over the Ruhr were achieved. Luftreinhaltung.

Böhringer, Christoph, and Andreas Löschel. 2005. "Climate Policy Beyond Kyoto: Quo Vadis?" Kyklos 58 (4). Wiley Online Library: 467–93.

Cheng, Beibei, Hancheng Dai, Peng Wang, Yang Xie, Li Chen, Daiqing Zhao, and Toshihiko Masui. 2016. "Impacts of Low-Carbon Power Policy on Carbon Mitigation in Guangdong Province, China." Energy Policy 88: 515–27.

Cheng, Beibei, Hancheng Dai, Peng Wang, Daiqing Zhao, and Toshihiko Masui. 2015. "Impacts of Carbon Trading Scheme on Air Pollutant Emissions in Guangdong Province of China." Energy for Sustainable Development 27: 174–85.

China Electricity Council. 2011. "China Electricity Statistics." Report.

China Hydropower Planning Institute. 2011. "Investment Cost Data of Hydro, Wind, Solar Pv and Biomass Power (Unpublished Internal Material)." Report.

Dai, Hancheng. 2012. "Integrated Assessment of China's Provincial Low Carbon Economy Development Towards 2030: Jiangxi Province as an Example." Ph.D. Dissertation, Tokyo Institute of Technology.

Dai, Hancheng, Toshihiko Masui, Yuzuru Matsuoka, and Shinichiro Fujimori. 2011. "Assessment of China's Climate Commitment and Non-Fossil Energy Plan Towards 2020 Using Hybrid AIM/CGE Model." Energy Policy 39 (5). Elsevier: 2875–87.

———. 2012. "The Impacts of China's Household Consumption Expenditure Patterns on Energy Demand and Carbon Emissions Towards 2050." Energy Policy 50: 736–50.

Dai, Hancheng, Xuxuan Xie, Yang Xie, Jian Liu, and Toshihiko Masui. 2016. "Green Growth: The Economic Impacts of Large-Scale Renewable Energy Development in China." Applied Energy 162: 435–49.

Dong, Huijuan, Hancheng Dai, Liang Dong, Tsuyoshi Fujita, Yong Geng, Zbigniew Klimont, Tsuyoshi Inoue, Shintaro Bunya, Minoru Fujii, and Toshihiko Masui. 2015. "Pursuing Air Pollutant Co-Benefits of CO2 Mitigation in China: A Provincial Leveled Analysis." Applied Energy 144. Elsevier: 165–74.

Fujimori, Shinichiro, Toshihiko Masui, and Yuzuru Matsuoka. 2015. "Gains from Emission Trading Under Multiple Stabilization Targets and Technological Constraints." Energy Economics 48. Elsevier: 306–15.

Beijixing dianliwang. (2017, 01 16). *NEA issued 13 provinces and cities to shut down construction of new coal power*. Retrieved from http://news.bjx.com.cn/html/20170116/803648.shtml

Hoornweg, D., & Bhada-Tata, P. (2012). *What a Waste : A Global Review of Solid Waste Management. Urban development series.* Washington, DC: World Bank.

Hu, Y., Hall, C., Wang, J., Feng, L., & Poisson, A. (2013). Energy return on investment (EROI) of China's conventional fossil fuels: historical and future trends. *Energy, 54*, 352-364.

Huang, W. (2006, March 21). Speech given at the meeting of "Building New Countryside of the Socialist Society.". *Ministry of Construction of China*. Beijing, China: Ministry of Construction of China.

MEP, NDRC, and NEA. (2015, 12 11). *Action Plan on Coal-fired Power Emission Reduction*. Retrieved from http://www.mep.gov.cn/gkml/hbb/bwj/201512/t20151215_319170.htm

National Bureau of Statistics of People's Republic of China. (2014). *2014 China Statistical Yearbook [M].* Beijing: China Statistics Press. .

NDRC. (2016, 12). *13th FYP for Power Sector Development*. Retrieved from http://www.ndrc.gov.cn/zcfb/zcfbghwb/201612/P020161222570036010274.pdf

NDRC. (2017, 04 17). *Suggestions Regarding Accomplishing Work on Overcapacity Problem Solving and Achieving Profitable Progression in Coal Industry in 2017*. Retrieved from http://www.ndrc.gov.cn/zcfb/zcfbtz/201705/t20170512_847276.html

NEA. (2012). *Resources Survey and Assessment Study on Crop Straw as a Source for Energy Utilization 2006. Research unit: The Planning and Design Institute of Ministry of Agriculture.* . Retrieved from http://www.nea.gov.cn/2012-02/10/c_131402402.htm

Song, J. (2012). Migrant employment in urban China: characteristics and determinants – a comparative study with rural left-behind people. *Population Research, 34(6)*, 32-42.

U.S. Department of Energy. (2011). *2010 buildings energy data book.* Silver Spring, MD: D&R International, Ltd.

United Nations. (2012). *UN World Urbanization Prospects, the 2011 Revision.* United Nations. United Nations.

United Nations. (2015). *World population projects, the 2015 Revision.* United Nations, Department of Economic and Social Affairs, Population Division. United Nations.

Beijixing dianliwang. (2017, 01 16). *NEA issued 13 provinces and cities to shut down construction of new coal power*. Retrieved from http://news.bjx.com.cn/html/20170116/803648.shtml

Hoornweg, D., & Bhada-Tata, P. (2012). *What a Waste : A Global Review of Solid Waste Management. Urban development series.* Washington, DC: World Bank.

Hu, Y., Hall, C., Wang, J., Feng, L., & Poisson, A. (2013). Energy return on investment (EROI) of China's conventional fossil fuels: historical and future trends. *Energy, 54*, 352-364.

Huang, W. (2006, March 21). Speech given at the meeting of "Building New Countryside of the Socialist Society.". *Ministry of Construction of China*. Beijing, China: Ministry of Construction of China.

MEP, NDRC, and NEA. (2015, 12 11). *Action Plan on Coal-fired Power Emission Reduction*. Retrieved from http://www.mep.gov.cn/gkml/hbb/bwj/201512/t20151215_319170.htm

National Bureau of Statistics of People's Republic of China. (2014). *2014 China Statistical Yearbook [M].* Beijing: China Statistics Press. .

NDRC. (2016, 12). *13th FYP for Power Sector Development*. Retrieved from http://www.ndrc.gov.cn/zcfb/zcfbghwb/201612/P020161222570036010274.pdf

NDRC. (2017, 04 17). *Suggestions Regarding Accomplishing Work on Overcapacity Problem Solving and Achieving Profitable Progression in Coal Industry in 2017*. Retrieved from http://www.ndrc.gov.cn/zcfb/zcfbtz/201705/t20170512_847276.html

NEA. (2012). *Resources Survey and Assessment Study on Crop Straw as a Source for Energy Utilization 2006. Research unit: The Planning and Design Institute of Ministry of Agriculture.* . Retrieved from http://www.nea.gov.cn/2012-02/10/c_131402402.htm

Song, J. (2012). Migrant employment in urban China: characteristics and determinants – a comparative study with rural left-behind people. *Population Research, 34(6)*, 32-42.

U.S. Department of Energy. (2011). *2010 buildings energy data book.* Silver Spring, MD: D&R International, Ltd.

United Nations. (2012). *UN World Urbanization Prospects, the 2011 Revision.* United Nations. United Nations.

United Nations. (2015). *World population projects, the 2015 Revision.* United Nations, Department of Economic and Social Affairs, Population Division. United Nations.

National Bureau of Statistics of China (NBS). 2008. China Energy Statistical Yearbook 2008. Beijing: China Statistics Press.

———. 2011. Input-Output Tables of China 2007 (in Chinese). Beijing: China Statistics Press.

Rutherford, Thomas F. 1999. "Applied General Equilibrium Modeling with Mpsge as a Gams Subsystem: An Overview of the Modeling Framework and Syntax." Computational Economics 14 (1-2). Springer: 1–46.

Taylor, R.P. 2015. A review of Industrial Restructuring in the Ruhr Valley and Relevant Points for China, Washington: Institute for Industrial Productivity.

Tian, Xu, Hancheng Dai, and Yong Geng. 2016. "Effect of Household Consumption Changes on Regional Low-Carbon Development: A Case Study of Shanghai." China Population, Resources and Environment 26 (5): 55–63.

Tian, Xu, Yong Geng, Hancheng Dai, Tsuyoshi Fujita, Rui Wu, Zhe Liu, Toshihiko Masui, and Yang Xie. 2016. "The Effects of Household Consumption Pattern on Regional Development: A Case Study of Shanghai." Energy 103. Elsevier: 49–60.

Wang, Ke, Can Wang, and Jining Chen. 2009. "Analysis of the Economic Impact of Different Chinese Climate Policy Options Based on a Cge Model Incorporating Endogenous Technological Change." Energy Policy 37 (8): 2930–40.

Wang, Peng, Hancheng Dai, Songyan Ren, Daiqing Zhao, and Toshihiko Masui. 2015. "Achieving Copenhagen Target Through Carbon Emission Trading: Economic Impacts Assessment in Guangdong Province of China." Energy 79: 212–27.

Xie, X. 2011. The value of health: Applications of choice experiment approach and urban air pollution control strategy. Peking University.

Zhang, Zhong Xiang. 1998. "Macroeconomic Effects of Co2 Emission Limits: A Computable General Equilibrium Analysis for China." Journal of Policy Modeling 20 (2): 213–50.

Part 3:

Energy transition measures

15 From Scenario to Strategy to Implementation

Globally, immediate actions are required to realize the goal established in the Paris Agreement to control the global temperature rise within 2 °C, and to avoid the path dependency and societal losses in the coming decades by continued establishment of traditional energy infrastructure. Europe and America have accumulated extensive practical experience in energy transition guided by the low-carbon development objective. As the largest country in terms of energy production and consumption in the world, and one of the largest countries with respect to future incremental energy demand, China must establish its long-term energy transformation strategy without delay, and guide the clean low-carbon energy transformation pathway to achieve a "Beautiful China" and the Below 2 °C target. It must set up industrial management and modern regulatory systems coordinated with the overall energy management departments and professional energy regulatory agencies to turn the global consensus into comprehensive actions, thereby embracing the age of renewable energy.

15.1 International Practice in and Lessons from Renewable Energy Strategy under the Low-carbon Objective

Overall Situation

Since 1970s, and especially since the beginning of this century, the international community has played increasing attention to finding solutions to climate change, energy security, ecological environment protection and other sustainable development issues. It has become a general consensus, subject of joint action globally, to accelerate the energy transformation, reduce the use of fossil energy, and promote the development and utilization of renewable energy. Recently, the International Energy Agency and International Renewable Energy Agency have put forward global roadmaps for high renewable energy penetration. The European Union, Denmark, Germany and California in the USA have taken lead in developing the roadmaps for the high renewable energy penetration development for 2030 and 2050. Over 600 cities at the Climate Conference in Paris (COP21) have committed to achieving 100% renewable energy, allowing the high renewable energy penetration to transition from scenario analyses into strategic implementation stage.

Table 15-1 Goal and key areas of renewable energy development in major countries (regions)

Country	Goal of renewable energy development	Goal realization mechanism, important reforms and policies
European Union	The renewable energy will account for 20% and 50% of the total energy consumption by 2020 and 2050, respectively.	A package of policies for energy, climate and environment (three 20%s; 27% by 2030); the member countries' goal commitment, report and evaluation mechanism; the uniform European electricity market; European carbon trading (ETS).
Germany	By 2020, 2030, 2040 and 2050, the renewable energy will account for 18%, 30%, 45% and 60% of the end-user energy consumption respectively, and the renewable electricity will account for 35%, 50%, 65% and 80% of the total electricity consumption respectively.	Wind power, photovoltaic power generation, energy storage; expansion of the power transmission network; cities of 100% renewable energy; fixed feed-in tariff (FIT) of the renewable energy; the renewable energy's involvement in the electricity market (direct marketing); market premium mechanism (FIP).
Denmark	The wind power will account for 50% of the total electricity consumption by 2020; the fossil energy will be totally abandoned by 2050.	Green heating system; promotion of the renewable energy to be applied in the construction, industry, and transportation fields; acceleration of the development of intelligent grid, improvement of the energy financing system, etc.
California, USA	By 2030, renewable generation share to be increased to 50%, the petroleum consumption reduced by 50%, building efficiency doubled; compared with 1990, GHG emissions in 2030 and 2050 reduced by 40% and 80% respectively.	Promotion of the development of solar power generation, wind power, biofuel and construction of intelligent grid; production tax credit (PTC) and investment tax credit (ITC); renewable portfolio standard(RPS).

Situation in Major Countries and Regions

The European Commission promulgated the Green Paper on EU Energy Strategy in 2006. In 2008, the EU Summit passed the Energy and Climate Package Plan, an energy legal system which sets up several short, medium and long-term goals based on the “20-20-20” directive: by 2020, the renewable energy will account for 20% of the total end-user energy consumption; compared with 1990, the GHG emissions will reduce by 20% and the energy efficiency will increase by 20%. In October 2014, the European Council approved the 2030 Climate and Energy Policy Framework to achieve the goal that, GHG emissions will be reduced by at least 40% from the 1990 level, and both the proportion of renewable energy and the energy efficiency will be increased to above 27% by 2030. In order to guarantee the implementation of the package plan, EU established a transparent management system to instruct the member countries to develop their renewable energy policies and laws under the "Renewable Energy Directive" of EU, and submitted the National Renewable Energy Action Plan to allow the European Environment Agency (EEA) and other agencies to evaluate the progress of member countries. EU also promotes the renewable energy to be driven by the market gradually. Since January 2016, all benefiting parties enjoying the subsidies for renewable energy generation shall sell the power to the market directly, participate in the market competition, and promote cancellation of subsidies for the mature renewable energy technologies in the 2020-2030 timeframe. According to EU, it shall give play to the potential of renewable energy technologies to keep reducing the price of energy in the market, which is the "essential factor for EU to construct a competitive, safe and sustainable energy system".60The EU also makes great effort to construct an integrated internal energy and electricity market to guarantee the interconnection among power grids and free trade of renewable electricity.

In February 2011, Denmark issued the 2050 Energy Strategy, as the first country in the world to develop a comprehensive strategy to totally eliminate dependence on fossil energy by 2050. The energy transformation strategy of Denmark emphasizes the replacement of fossil energy and all-round development and utilization of renewable energy. It focuses on expanding the large-scale development of wind power in the renewable energy field, increasing the utilization of biomass energy, expanding district heating, limiting and replacing the utilization of fossil energy in end use consumption. Since 2013, the new buildings are prohibited to install the gas-fired boilers or oil-fired boilers in Denmark. Since 2016, it is also prohibited to install and use the oil-fired boilers within the existing buildings in the area zone with centralized heating solutions. Denmark also promotes the integration of the electricity and heating systems, advocates effectively improving the flexibility of the heating system and the efficiency of the whole energy system. This includes the use of electric boilers and heat pumps, which can support the power system by using more wind power, to address the challenge arising out of the increasing proportion held by renewable energy in the power system.

In September 2010, Germany published the Energy Program of the German Federal Government to achieve the goal that, by 2050, GHG emissions shall be reduced to at most 80% of the 1990 level, and the proportion of renewable energy in the end-user energy consumption and the proportion of renewable electricity in the total electricity consumption should be increased to above 60% and 80%, respectively. For this purpose,

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60 EU,A Policy framework for climate and energy in the period from 2020-2030, dated 22.1.2014

Germany established the "Energiewende" (energy transformation) monitoring system in October 2011, set up an independent committee to supervise and evaluate the monitoring system, and publish annual monitoring reports as well as evaluation reports on the three-year progress. Since the end of the last century, Germany promulgated several laws to support the energy transformation, for example, it successively promulgated and revised the Renewable Energy Law, Renewable Energy Heating Promotion Law, Law on Accelerating Network Construction (NABEG), amendment to Cogeneration Law (KWK-G) and other laws and regulations, which establishes the legal track for energy transformation. In order to promote the energy reform in an all-round way, Germany established the departmental roadmap and the comprehensive energy system transformation roadmap, considered the synergistic effect of energy transformation in the industrial, commercial, transportation and construction departments etc. It launched the "digital agenda for energy transformation" (SINTEG) project covering the electric, heating power, transportation energy and other energy fields, constructed the future energy system of intelligent energy supply and utilization, and improved the flexibility of energy system, so as to guarantee to utilize wind power, photovoltaic energy and other variable renewable energy. Furthermore, Germany also vigorously promotes the regional and urban energy transformation, and provides the solutions covering from the national level to the local level. For example, Frankfurt established the "overall planning for 100% climate protection", aiming to, by 2050, supply 100% of urban consumed energy (including power supply, heat supply and transportation) through renewable energy, reduce the total urban energy consumption to 50% of that in 2010, and further promote 95% reduction of annual GHG emissions relative to 1990. For this purpose, the municipal government will focus on the reconstruction and upgrading of the electricity, heating and transportation fields.

California is at the leading edge of renewable energy in USA as well as internationally. According to SB 350 Act of California (2015 Clean Energy and Pollutant Emission Reduction Act), the market shares of renewable electricity (RPS) is required to increase to 40%, 45% and 50% in 2024, 2027 and 2030, respectively. The petroleum consumption shall be reduced by 50%, and the building efficiency shall be doubled. Compared with 1990, GHG emissions in 2030 and 2050 shall be reduced by 40% and 80%, respectively. The California Energy Commission (CEC), California Public Utilities Commission (CPUC) and California Independent System Operator (CAISO) are responsible for developing the specific policies and schemes, and for establishing and operating the open and competitive electricity market in California, which promotes the development of wind power, photovoltaics, electric vehicles and other new energy technologies. In particular, CAISO provides the policy makers and the industrial circle with the timely and accurate power market forecasting, the information related to the power system operation and real-time market data, which provides a basis for the planning, investment and construction of the future power system. Based on the planning study of the power system and simulation analysis on the competitive power market, CAISO screens projects through the project list study (cluster study), gives priority to the projects with minimum system costs or the projects whose users intend to pay the additional construction costs. Fast channels are open to small projects. In recent years, as the proportions of solar photovoltaic power generation, wind power and other new energy increased, CAISO has enhanced its coordinated control on the surrounding power balance areas through equal consultation, expanded the real-time market transactions, expanded power balancing to more areas, constructed a cross-market energy imbalance market (EIM), and strived to turn CAISO into a regional market organization.

Realisation

The long-term energy, climate and environment goals shall guide the long-term roadmap for energy transformation. Europe, Denmark, Germany and California in the USA insist on developing the renewable energy under the guidance of the long-term climate and environment goals for 2050.They carry out the energy transition with top-level design and goal guidance in a practical way. Generally speaking, the EU, Denmark, Germany and California establish the integrated energy and climate policy based on the low-carbon development goal for 2050, thereby setting a clear transformation goal and path for low-carbon energy, guidance and acceleration of the development of renewable energy, promotion of the energy structural transformation and end-user energy consumption revolution, to eliminate the use of fossil energy. In the process of implementation, these countries and states decompose their goals, promote the joint action, carry out assessments, and establish the policy guarantees and dynamic adjustment mechanisms for different industries and departments.

To achieve the common goal of energy transition and maintaining global temperature increases below the Below 2 °C target, high renewable energy penetration shall be at the forefront of the energy structural transformation. The overall strategy shall be implemented through regional/urban/departmental energy transformation actions. All countries must pay close attention to the energy transformation strategy centred on the electricity and innovate in the end-user departmental energy replacement, intelligent infrastructure, modern electricity market systems and new regulatory systems. They shall establish good coordination mechanisms, collect input from interested parties from the bottom up, and put the policies into implementation from the top down.

The development of renewable energy shall be guaranteed through laws, regulations and market mechanism innovation. The energy transformation strategy of EU countries sets out the medium and long-term goals and implementation policies for energy transformation, and it also pays continuous attention to the energy legislation and the design of systems and mechanisms. Germany and other countries establish the detailed regulations on the development goal of new energy with respect to legislation, and make the supporting legislation on power enterprises' utilization of new energy as well as the grid connection of renewable electricity. The strategic planning and legal documents related to energy transformation improve the predictability, continuity and operability of energy policies, guarantee the implementation effect, and lay a solid policy foundation for energy transformation.

15.2 A Package of Plans on Energy, Climate and Environment in China

In the formulation of an energy development strategy and the construction of future energy systems in China, it is necessary to take a long-term perspective, seize the opportunity of global energy transformation and technological advancement to put renewable energy into a more important position and strengthen top-level design, in order to realise the revolution of energy production and consumption. The Strategy on Revolution of Energy Production and Consumption (2030) issued by the Chinese government in 2016 has formally put forward the long-term goal of having more than half of the energy come from non-fossil energy sources by 2050. Based on rapid advancement of the technological industry, rich international practical experience and the analysis of the Below 2°C scenario, the proportion of renewable energy in China's primary energy can be increased to 54% in 2050 by reforming the supply and demand side energy system, releasing the flexibility of the system and making market and system innovation exert motivation by providing incentives. Therefore, China needs to follow the global trend of green and low-carbon development and implement the new development idea of "innovation, coordination, green, opening-up and share". In order to utilize renewable energy as the main source of energy and realise the energy revolution, building up a modern energy system before 2050, China needs to adopt systematic views and insist on the orientation of goal, problem and action. Centred on market reform and system construction, promoting the scenario of high renewable energy penetration should be implemented into the renewable energy development strategy system.

China needs to develop strategies for energy, climate and the environment towards 2050. To bring ecological civilization construction into a five-in-one layout, China needs to strengthen the three-line restrains in resources, environment and ecology. China needs to strictly control the scale, layout and way of fossil energy production and final consumption. Specifically, China needs to approve further coal exploration, discontinue and replace final coal consumption, control coal power capacity and implement environmental standards and flexibility transformation. To stay in accordance with the mechanisms for independent emission reduction, continued global five-year checks and constant improvement of goals defined in the Paris Agreement are needed. China needs long-term strategic goals and ways of reducing emission of GHG and consumption of coal, oil and gas in order to promote leapfrog development of non-fossil energy and achieve the goals for 2050 proposed in the aforementioned Strategy on Revolution of Energy Production and Consumption (2030), in which the development roadmap of high renewable energy penetration is formulated.

By giving priority to develop and utilize renewable energy consistently, promoting renewable energy going into the transition period of the energy revolution from regional incremental replacement to overall existing replacement before 2030, the new energy system centred on renewable energy can by formed by 2050. Meanwhile, China needs to ensure that the proportion of the renewable energy in the primary energy consumption grows to over 55% and ensure that the proportion of renewable energy power generation in total power generation reaches over 85%. In order to realize fundamental change of the ways of replacement, exploration and utilization of the main energy sources in China, the government needs to fundamentally resolve the contradictions between energy resources and environmental constraints, ensure energy security and realize sustainable development of the economy and society.

A renewable energy goal guidance system and an implementation mechanism coordinated by central and local governments should be established. In accordance with the Renewable Energy Law, the medium -term and long-term goals of exploration and utilization of renewable energy in China in 2030 and 2050 should be set, including both the goal of the proportion of the renewable energy in primary energy consumption and the goal of the proportion of the renewable energy in nationwide power generation, heat supply and energy consumption of the transportation sector. In accordance with the nationwide goals, the development level of the economy, society and environment of various provinces (regions and cities) and the renewable energy level, set the minimum goal of the proportion of the renewable energy of various provinces (regions and cities) and encourage various provinces (regions and cities) to set more ambitious goals for themselves. The national energy administrative departments shall organize the establishment of the system of monitoring, appraisal and evaluation of renewable energy throughout the country in various provinces and regions and publicize the results. The national energy administrative departments and various provinces (regions and cities) shall take the lead in formulating and implementing the quota system, in which the market subjects undertake specific index obligations and liabilities (proportion goal implementation mechanism). Encourage various provinces to establish the system on heat enforcement installation or requirement to heat supply proportion of renewable energy used for newly-built buildings and industry.

Sustainable investment environment of renewable energy shall be established. Large-scale renewable energy development needs more investment and investors to focus on long-term returns of energy transformation rather than short-term profits. Public institutions shall establish stable system of policies and regulations on renewable energy, aiming at forming a stable investment environment by virtue of transparent all-round policies. It is necessary to reduce the subsidy for huge volume of fossil fuel, promote fair play, develop public-private partnership (PPP), and promote the innovation of financial market facilities, so as to create a new industrial ecology for renewable energy.

The renewable energy goal guidance system and the total energy consumption control goal system shall be linked up, setting bottom target for but without cap on renewable energy. The reform scheme on ecological civilization system of China proposes to establish the system of management of total energy consumption and energy saving and suggests formulating the control goal of total consumption of fossil energy and action plan to enable coal consumption, coal power installed capacity and oil consumption to reach their peaks respectively before 2020, in 2020 and in 2025. As for major industrial sectors and enterprises, the renewable energy consumption proportion goal is proposed in an energy-saving scheme. In total energy consumption, it's necessary to set a lower limiting value for renewable energy but no upper limiting value, and offset equal fossil energy consumption.

Total carbon emission cap shall be strictly set to expand the coverage of carbon trading and strengthen the restriction of carbon trading market to fossil energy consumption and cost coverage. The ecological civilization system reform scheme proposes to establish the system of controlling total emission of carbon and the mechanism of division and implementation. *Interim Measures for the Administration of Carbon Emission Permit Trading* issued by the National Development and Reform Commission on December 10, 2014 requires to define the total quota emission of the country, various provinces, autonomous regions and municipalities directly under the Central Government according to the requirements of national goal of controlling GHG emission. Emission quota shall be allocated mainly free of charge in the initial period, paid allocation shall be introduced in appropriate time, and the proportion of paid allocation shall be improved gradually. The income from paid allocation will be used for promoting construction of national carbon reduction capacity and other relevant capacities. Based on carbon trading pilot areas in seven provinces, China will start carbon trading pilot areas nationwide in 2017. The followings are suggested: (1) Based on controlling of total carbon emission nationwide, further improve the coverage of carbon trading market, and in most conditions, set goals and reduce exempt enterprises and limit according to "pacemaker" industrial standard. (2) Improve the proportion of paid issuance (auction) of carbon emission permits and exert the effective distribution mechanism of auctioning as primary market and pricing way, in order to realize "double dividends". Through buy-back and carbon tax measures, etc., increase the carbon price steadily and increase consumption cost of fossil energy gradually. (3) Expand the scope of renewable energy CCER project involved in carbon trading and promote emission-control enterprises to give priority to developing and utilizing renewable energy.

15.3 Trans-Sector Roadmap Enabling Flexible Energy System

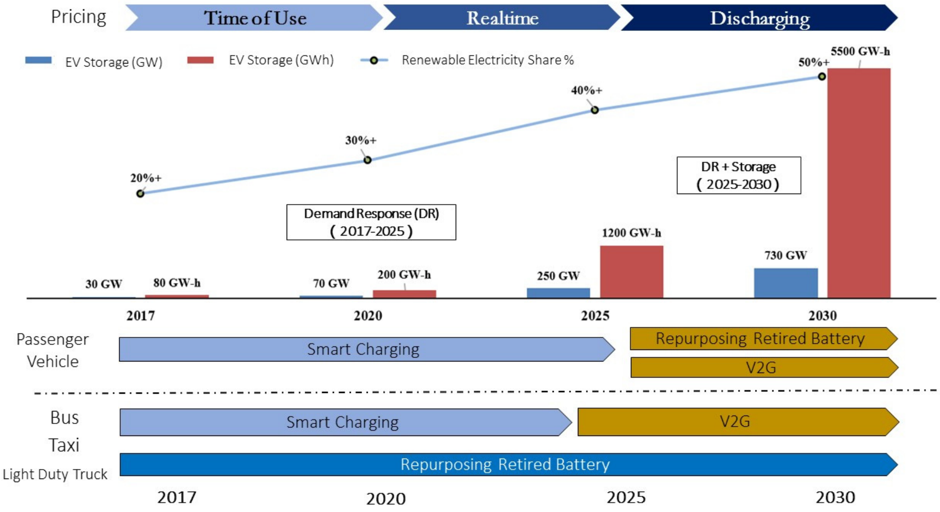
Energy system development has great inertia. The dominant position and competitive advantages of main categories of energy and energy technologies have formed in the aspects of infrastructure, standards and codes, market mechanism, management system and even laws and regulations. Energy development is path dependent to some extent. The energy infrastructure being built will decide the energy development path through the coming 20-40 years. The energy demand of China continually increases, and investment demand is significant. Societal risks and losses may be great, if the energy fails to be accelerated and transformed to clean low-carbon energy including renewable energy. Therefore, to deal with climate change, it is required to overcome the lock-in risk of energy system technology as soon as possible, and deploy a long-term energy transformation strategy and meet the era of renewable energy proactively.

Efforts are needed to build up a modern energy system centred on renewable energy, complying with the features of new energy and meeting the energy revolution requirements by 2050. The "system perspective" is adopted to guide energy system transformation by high renewable energy penetration. As for unfavourable coordination and poor efficiency of energy system, it is required to implement new development ideas, insist on energy reform in both supply and demand, promote final energy consumption and energy production transformation in the sectors of architecture, industry, transportation, power and heat production, and to confirm the main direction, technology approach and space layout of gradual replacement of fossil energy by renewable energy; and to promote optimized layout and efficient utilization of new and existing energy and power production project, market space and transmission channels.

Renewable energy and urban infrastructure and utilities (on power heat and gas supply) shall develop in a coordinative way. In the regions with abundant resources, renewable energy has become the main energy source for central heating in some cities. At present, such successful cases on heat supply in cities indicate that renewable energy as main energy source for central heating in the city can be supported by technology and market conditions. However, single categories of renewable energy struggle to meet the demand of heat supply for urban buildings, so the multi-functional, complementary and integrated system combining urban resources and production and living features is very important. In addition, with constantly-increased proportion of renewable energy power, flexibility of power grid and heat supply network shall meet higher requirements. The technologies for heat supply network flexibility such as heat storage, electric boiler, heat pump and turbine bypass can improve the flexibility of regional heat supply and heat-power production system and support the flexibility of power in an improved way. Therefore, it is necessary to plan as a whole to construct and transform the infrastructure for urban heat supply, strengthen construction and transformation of supporting power grid and optimize the design of heat supply networks. That's how a comprehensive heat supply system, featured by coordination, complementation and gradient utilization between renewable energy and traditional energy, can be established.

Renewable energy power generation and electric vehicles in transportation sector shall develop in a coordinative way. Both renewable energy and electric vehicles are strategic emerging industries and have great potential of coordination. Well-organized access to electric vehicles will improve the consumption capacity of power system to volatility renewable energy, reduce the power of wind curtailment and photovoltaic power curtailment and decrease production cost and the emission level of pollutants and carbon. Well-organized guidance to charging load of electric vehicles can reduce the peak difference of the power system load, improve the operation effectiveness of generation unit and save generation capacity investment and fuel cost. Flexible charging and discharging of electric vehicles can be ancillary service resources and reduce the cost of ancillary service provision. Effective management of charging of electric vehicles will avoid or delay the investment cost of power transmission and distribution to some extent. Although power supply in most regions of China is still mainly in coal power, it is necessary to lay out the coordinative development between renewable energy and electric vehicles as early as possible, by dynamic coordination and sound development of their own industries. Through a well-organised connection of renewable energy and vehicle charging the initial targets for 2020 are economic and environmental value in key areas promoting coordination of renewable energy and electric vehicles. Furthermore, the targets for 2030 include V2G and ex-service battery storage capacity through coordinated development of renewable energy and electric vehicles (Figure 15-1).

Figure 15-1 Roadmap of coordinated development of new energy power generation and electric vehicles



15.4 Integrated Administration and Specialized Regulatory System

Transforming the governmental functions and boosting the reform of streamline administration

China's current management system of the energy industry developed through the former planned economy system. China has designated different administration departments such links as resource exploration administrator, project/grid investment and construction administrator, administrator on energy production, transportation and pricing; Furthermore, separate construction administration system for different kinds of energy products and technologies such as coal, oil & gas, power and grid, nuclear power and new energy, in order to ensure security of energy supply. On one hand, the government has controlled the micro-operation of all industries through administrative means for a long time. On the other hand, the government has not established the administration and regulatory system that promotes efficient energy system transformation and effective market competition. More seriously, important issues such as public infrastructure planning, regulation of electric grid and gas pipeline access, formulation of standards and specifications, etc., have been done by largely depending on the large power grid and oil & gas enterprises with monopoly characteristics, which certainly weakens the government's supervision capability and inhibits the decisive role that the market shall play. In general, the planned economy characteristics and traditional structure of China's current energy administration have hindered the effectiveness of energy system transformation. The lack of a modern regulatory system, unequal power and responsibilities and even responsibilities without authority restrain the regulators' capacity of maintaining open and fair market competition.

With the comprehensive transformation of China's economic development mode to the socialist market economy and shift of the focus of energy development from energy supply security to the sustainable energy development, China needs to deepen the reform of the energy management system within the shortest time possible. Following the 18th National Congress of the Communist Party of China, Chinese government pointed out explicitly that the core of economic system reform lies in dealing with the relationship between the government and market properly, so that the market could play a decisive role in resources allocation and better exert the functions of government. To transform government functions, the core is deepening administrative system reform by following the general requirements of "streamline administration, delegate powers, and improve regulation and services". The main tasks for the reform of Chinese energy management system are to adapt to the requirement of market-oriented reform and reduce the direct control by government on investment, price and operation of specific energy power projects, while establishing market-oriented system of price formation with a faster speed to guide enterprises' investment and operation of power system. Instead, attention will be paid to the in-process and after-event regulation on the preparation and execution of strategic planning, policies and regulations, market rules, standards, strengthening of macro comprehensive management and micro-specialized supervision under the collaboration of central and local governments, and establishment of integrated administration system coordinating energy system transformation and maintaining open and fair market order in order to realize "synchronous decentralization of power and responsibilities and synchronous strengthening of regulation and supervision", in order to create a unified, fair and open competition market environment, strengthen governance reform and monopoly supervision of enterprises with administrative and natural monopoly characteristics, and release the huge potential of energy enterprises, users, residents and other market entities in investing, constructing projects and producing, consuming green renewable energy.

Establishing an integrated energy administration system that promotes systematic transformation with collaboration of central and local governments

An administration framework collaborated by central and local governments shall be established to guide the local energy transformations through national objectives and basic rules. The responsibilities of the central and local governments in promoting energy system transformation and development and utilization of renewable energy shall be further defined, the system with equal responsibilities, power of office and power of property shall be established and "Two Positivity's" of the central and local governments shall be exerted according to the central and local authority division-based governance principle of "externality, information advantage and incentive compatibility", in order to promote energy transformation with joint efforts. As explicitly specified in Opinions on Further Reforming the Government Administration System, "the central government shall strengthen the macro management of economic and social affairs, further reduce and decentralize the specific administration matters, switch attention to the preparation of strategic planning, policies and regulations, and standards and specifications, maintain the unification of legal system, government decrees and market, integrate and improve industrial administration system, and exert the role of industrial administration departments in preparing and organizing the implementation of industrial policies, industrial planning and national standards". Under the aforementioned principle and guiding opinions, the central government shall be responsible for strengthening macro administration (the overall and multi-provincial issues), top-level design and implementation of specialized regulatory system. In particular, the authorities in charge of economy, energy and climate environment shall promote the energy administration system reform and energy/environment market system reform synchronously, such as establishing market transaction and pricing rules that are able to reflect market demand & supply as well as resources and environmental cost, while removing the threshold for the investments of energy projects such as coal power and wind power comprehensively. National energy administrators and regulators shall strengthen the guide of national total amount target and structural improvement, establish and promote the basic public fiscal revenue and tax preference policies of technical industrial innovation and national resources optimized development, plan and organize the construction of interconnected trans-provincial and trans-regional energy management network, prepare and implement basic market rules for ensuring open and fair competition and strengthen the strict supervision of monopoly links such as energy management networks and dispatching organisation, by such means as strategic planning and appraisal. The energy authority below provincial level shall, by considering their realities, prepare more targeted and efficient implementation mechanism, specific planning, action plan, implementation plan and economic incentive policies for the local renewable resource objective by organising relevant parties, in order to provide favourable conditions for enterprises and residents to develop renewable resources.

China shall break through energy product/technology-specific administration and establish an integrated administration system, which is beneficial to energy system transformation. Following the principle of "implementing "three-line" concept, coordinating spatial layout and breaking market division", the integrated administrators shall coordinate the development and utilization strategies, planning, policies and market rules of resources in different energy varieties effectively, connect energy development planning with basic strategic planning and policies regarding economic and social development, natural ecological environmental protection, state land spatial layout, urban and rural infrastructure construction, in order to give priority to renewable energy power generation, heat supply and fuel facilities which are more ecological and environmental friendly, and promote renewable energy in multi-energy complementation, open competition and gradual replacement with traditional coal, power, oil and gas products .

Firstly, establish "unified, public and open" planning working mechanism; for instance, the power system independent operation organization or other independent research planning organizations entrusted by the government organize all kinds of power generation enterprises, power grid enterprises and power users' representatives as well as representatives in ecological environment field to carry out planning in a public and transparent manner.

Secondly, carry out scientific planning by maximizing system efficiency and change the evaluation and planning method for the isolated project, base and channel; in particular, for the utilization of renewable energy power, the classification and planning mechanism of all kinds of powers and power grid channels, such as thermal power, nuclear power, hydropower and power transmission and distribution grid shall be replaced by the power system evaluation planning of provincial or regional level in order to ensure the flexibility of power system within a broader range and reduce the consumption of fossil energy.

Thirdly, strengthen the guiding and supporting role of public infrastructures such as grid, realizing "power grid construction promoted by power development, power development guided by power grid construction" by insisting on the principle of "reasonable layout, proper advancement and step-based implementation", particularly the fast development of new load such as all kinds of central and distributive new energy and electric vehicles, strengthen the planning and construction of power transmission channel of renewable energy base and accelerate the planning and construction, and transformation and upgrading of urban power distribution network.

Fourthly, integrate new energies such as distributed wind power, distributed photovoltaic power and geothermal energy into urban and rural spatial planning system by combining the municipal and county "all regulations in one" pilot and connect them with urban and rural development planning, land utilization planning and specific controlling plan to promote the efficient development and utilization of distributed energy.

The administrator needs to promote the reform of investment and operation administration adaptive to market-oriented economic reform, following the principles of "loosening economic control, strengthening social control and improving the restrictions of standards and specifications". All projects, except for large hydropower projects related to national security, ecological safety, development of strategic resources and national major productivity distribution, shall be decided independently by enterprises as per laws and regulations instead of being approved by the government. With the popularity of constructing small and medium-sized renewable resources project, it is a MUST to adapt to the characteristics of renewable energy projects, including relatively small scale, scattered layout and diversified investment and construction operation subjects. Furthermore, to smoothen and simplify management process, improve project management service platform, promote, guarantee and attract the whole society to invest renewable energy projects as much as possible and in particular, promote local private capital to actively participate in renewable investment and cultivate and develop diversified market players .

Establishing a modern specialized regulatory system well matching with integrated energy administration and market-oriented reform

China's current regulatory system has hindered the process of energy transformation and market-oriented reform. Instead, specialized regulatory system at micro level must be established and improved regarding monitoring and supervision of energy strategies implementation, planning and competition policies, and particularly the strict supervision of cost and price, market access and admission, market competition. When preparing market admission and operation rules, energy administrators and regulators at all levels shall implement fair competition review system, keep improving and innovating supervision organization system, establish "integral supervision" consisting of government supervision, self-supervision of industries and enterprises and third-party supervision by referring to the international mature practice of "response supervision" and build multi-party cooperation mechanism so that the government is transformed from unique regulator to supervision organization. According to the requirements of new business environment and modes such as modern competition market system, trans-department multi-energy complementation and smart energy, regulators need to enrich technical and economic supervision approach and tools, form digital, standardized, normalized and specialized supervision mode and tools, and ensure the fairness and transparency.

A specialized regulatory system is urgently needed in the power market. It can be observed through foreign experience that the power grid access, wholesales market and retailing market of power market require strict and comprehensive supervision. Supervising mechanisms play a fundamental role in ensuring the normal operation of power market. The publication and prejudice-free openness of power transmission and distribution network is the top issue for the grid connection of renewable resources, without which, other issues are hardly meaningful. Power grids shall welcome all power generators in a fair and open manner, which means it needs to provide non-discriminatory access conditions. The key measures concern establishing reasonable organisational structure and regulatory system of such public service platforms as power grid infrastructure and transaction dispatch, as well as the issues fully concerned and resolved by all countries to boost energy transformation and power market-oriented reform. For instance, US FERC No. 888 urged public utilities enterprises to split power generation and transmission business and encouraged the establishment of independent system operation agency (ISO). The most basic features and functions of regional transmission organization, RTO, were determined and procedures were established in FERC No. 2000 thereafter, where public utilities enterprises with power transmission grid were encouraged to establish regional transmission organization (RTO) on a voluntary basis. FERC No. 890 decree required power transmission companies opened their power transmission planning process to clients, to coordinate with clients on the future system planning and to share necessary planning information with the client to increase the clients' capacity of using the newly established power generation resources fully and promote the efficient utilization of power transmission grid.

At present, China's power grid enterprises not only hold power transmission, distribution and sales business but also grasp the dominant control of power grid access, use of power transmission channel and planning of power and power grid system planning, lacking public scrutiny, transparency and broad in-depth participation of relevant parties. China shall further implement the spirit of Document No. 9 on power market reform by collecting the public power of power enterprises (particularly power grid enterprises), including such administrative power that shall have been exercised by the government as power grid planning, standards and grid connection and admission, to return the power grid to the enterprise's original role. The power grid enterprise's power transmission and distribution business shall be separated from power sales business and independent system operation organization separating from operating business shall be established. The public governance mechanism of power grid enterprises and transaction dispatching organization shall be improved, public and social supervision strength shall be introduced. This includes independent directors and representatives such as government, relevant parties of power industry and independent experts to ensure the power transmission and power grid enterprises can develop power transmission planning, transaction dispatching and information disclosure in an open and transparent manner.

15.5 Laws and Regulations promoting Renewable Energy and Reform

Legislation First and Coordinating Legislation and Law Revision

International experience supports that the legislations first policy promotes the development and market-oriented reform of renewable energy. The *Public Utility Regulatory Policies Act 1978* (PURPA) released in the United States defines the legal status of "qualifying facilities" for the small-scale power generation facilities of renewable energy, which requires the electric public utility enterprises to apply qualifying facilities for grid synchronization and provide reserve power supply to them. The *Energy Policy Act 1992* further empowers the Federal Energy Regulatory Commission (FERC) to order the power public utility enterprises that possess the transmission facilities to provide the transmission service of wholesale power selling to the independent power producers, ensuring the legal protection for the wholesale power market. The *Energy Policy Act 2005* stipulates that the electric public utility enterprises are obliged to provide the grid synchronization service for the power consumers who possess the distributive power generation facilities. Upon any request from customers, they shall also calculate the net amount of power for them. The energy and power market-oriented reform of the European Union also lies in the legislation first policy. Several directives and regulations have been released to form the community legal frame with all efforts, such as *The Second Gas Directive*, *The Second Power Directive*, the *Electric Power Regulation* and the *Gas Power Regulation*, which help to break the regional monopoly and promote more open and competitive power and gas markets. Article 18 of the *Directive on the Promotion of Electricity Produced from Renewable Energy Sources in the Internal Electricity Market* released in September 2001 stipulates the use of market power and effects of the internal market, showing an example for China where interprovincial monopoly is serious.

At the end of the 20th century, China set about pushing forward the sustainable energy development by legislation. However, the energy legislation process and construction of the legislation system is far behind the industrial development and other significant reforms, which is reflected through the ineffective force of administrative laws, regulations and department regulations (regulations of local governments). As the basic law of energy, the *Energy Law* is still absent, as well as the *Regulation on Energy Supervision* that shall be an important legal support for supervision. Of particularly importance is that the revision of relevant laws in the original energy and power fields lags far behind. The special laws of power etc. still feature the planned economy, which is completely uncoordinated with the requirements of energy transformation development and market-oriented reform, and even hinders the energy transformation and development in practice. Therefore, the energy transformation, new energy development, and system reform must be inducted into legislation to provide the legal supports for the development and system transformation of renewable energy. In this way, all parts concerned shall transform themselves based on rights and obligations that are regulated by laws. On one hand, the scientific legislation must be based on "Right First" principle, to define and protect objectively and reasonably the renewable energy and the rights of all parties concerned. On the other hand, the priority of work shall transform from "Authorization" in the past to "Responsibility Assumption" to define power and responsibilities in a scientific and reasonable way. That is, the energy administration and supervision organizations shall be granted to essential authority and assume the specific responsibilities at the same time, and the departments and local governments shall have access to authority in a defined range.

China shall always accelerate legislation and law revision in a coordinative manner. As China promotes the implementation and revision process of the *Renewable Energy Law*, China should simultaneously, or even in advance thereof, facilitate legislation and revision of the basic laws and relevant essential laws such as the *Energy Law* and *Electric Power Law*. The basic laws such as the *Energy Law* shall define the strategic and priority status of renewable energy, and build a development frame for renewable energy. The *Renewable Energy Law* shall be specified to reinforce itself in implementation. China shall enhance the integration and mutual effects of legislation and reform to implement the reform measures on the basis of the *Renewable Energy Law*, and perform the law revision, legal explanation, applicability improvement, or special authorization for the outdated content that is not applicable to the new situation in the *Electric Power Law*, especially in terms of regulations on the construction of the opening power grid without discrimination, independent transaction and dispatch organizations, power allocation and selling involved by the distributed power generation. The local governments shall be encouraged to make local laws and regulations for energy transformation. China is a single-system country where the central government has the exclusive power for legislation. As the central government is in the dominant position for legislation, all local governments are subject to and derive the legislative authority from the central government. The legislative authority of the local governments are used to serve the legislation of the central government or some local affairs only. The administrative regulations mainly refer to the regulations formulated by the departments of the State Council, provincial (autonomous regions, municipalities directly under the central government) people's governments, the governments in the cities where the provincial governments are located, and the people's governments of the major cities that are approved by the State Council. The supervision rules and regulations shall be formulated and introduced as soon as possible. They shall define the status, function, duties and responsibilities of the supervision organizations and set up supervision procedures and policy-making mechanisms as well as standardize the information disclosure requirements and dispute resolution mechanism.

Performance ability and Enforcement of Renewable Energy Law

The *Renewable Energy Law* needs to be improved in terms of its implementation effectiveness. The *Renewable Energy Law*, issued and implemented in 2005 and then revised in 2009, is an outstanding example for legislation of energy transformation in China. It stipulates that "*The state shall give priority to the development and utilization of renewable energy in energy development".* The formulation of the national and provincial long-term and medium-term total targets and planning for the development and utilization of renewable energy, defines the proportion of power generation capacity of renewable energy in the total power generation capacity, and implements the full-amount and safeguard purchase system of renewable energy. The price differences of the power grid enterprises shall be compensated by imposing the electricity prices of renewable energy on the electricity capacity for sales nationwide, and the financial authorities of the state shall set up a fund for the development of renewable energy. The power grid enterprises, gas enterprises, heat enterprises, and petrol enterprises who fail to purchase the renewable energy products according to the regulations shall be liable for such losses and shall be fined. However, it is still a serious problem that the enterprises who have failed to pay the additional fees and failed to purchase the electricity/heat/gas products of renewable energy have not been punished legally, the local governments also failed to enforce the regulations.

The reinforcement of the *Renewable Energy Law* lies in the legal layers and implementation intensity of the grid synchronization system. For the regulation implementation mentioned above, the relevant regulations of renewable energy are mainly issued and carried out by the departments or local governments through regulations, methods, detailed rules, and notices, which indicate the legal effectiveness at the lowest level when compared with the whole system of laws and regulations. In terms of the constitution of the legal system, the *Renewable Energy Law* only stipulates in general and in principle the full-amount and safeguard purchase system and penalty provision, while in practice, the regulations and methods rather than the law are enforced, and the transparent and detailed implementation rules are absent for the power grid enterprises and dispatch organizations. In some countries, such as the United States and Germany, the legal system of new energy grid synchronization consists of laws and administrative regulations stipulated by the corresponding electricity grid supervision organizations. Some items remain to be specified and clarified by FERC in meanings, but the laws and regulations of the gird synchronization have been endowed with sufficient executive forces and performance ability when referring to legislation purpose of the law.

The formulation of local regulations shall be accelerated. For energy transformation development in different regions, based on the *Legislation Law*, China shall encourage the provincial (autonomous regions, municipalities directly under the central government) governments to regulate relevant local regulations according to the specific situations and practical requirements of the energy transformation. China shall consider how to work out the specific regulations with powerful legal effectiveness to promote the development of energy transformation in terms of total target system, full-amount and safeguard purchase system, requirements for the electricity proportion of renewable energy, the heating proportion of renewable energy, construction of high renewable energy penetration areas on the basis the *Renewable Energy Law*. The cities where districts have been planned can also formulate the local regulations to build cities of high renewable energy penetration.

Revising the Electric Power Law in accordance with Market Principle[61,62]

In the middle of 1990s, the reform target for the socialist market economy system was established and China entered into an era where the reform of the economic system began to be promoted comprehensively. In 1997, the *Electric Power Law* was issued in China to formulate the opening of power resource investment, separation of enterprises from administration, separation of power grid from industry, which institutionally endows the enlargement of power investment with power and safeguard. However, the *Electric Power Law* and its corresponding regulations have become increasingly inappropriate for the market-oriented reform and requirements of new energy power development in recent 20 years. At present, the revision of the *Electric Power Law* is highly anticipated. The *Opinions of the CPC Central Committee and the State Council on Further Deepening the Reform of the Electric Power System* (ZF[2015]No.9) was issued in 2015 to formulate the establishment of sound energy legal system, establishment of the sound market system for the power industry with a legal support, acceleration of revision of the *Electric Power Law* and the study and drafting of its relevant administrative regulations, which accelerates the legalization for the departments such as the power department with new motivation.

To adapt to a new-round reform of power system and meet the demands of transformation and upgrade of the national energy system, the *Electric Power Law* shall define the basic guideline and system framework for the modern electric power market system, help the formation of the effective and competitive market structure and market system, and especially ensure that the synchronized power price and price of final sale are determined by market competition, while the transmission price and distribution price are set by the government. Since the pilot project is an important method to promote reform and verify the current power administration system in effect, it will certainly break the current system

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[61] Liu Chunrui and Liu Jin, Principles and Key Points of Revision and Compiling of the *Electric Power Law* Under the Background of Power Reform,*China Power Enterprise Management*, 2016, Issue 12

[62] Dong Xi and Zhao Zhonglong, Revision of the *Electric Power Law* at a Right Time, *Legal Person*,2015,Issue 7

frame and legal frame. Therefore, the *Electric Power Law* shall support the pilot project of power reform with legal space and basis.

With respect to the new energy development tendency and construction requirement of the power market, the *Electric Power Law* shall be mainly revised in the following aspects:

1) The current *Electric Power Law* stipulates that the subject of power production must be qualified as the independent legal person. This stipulation shall be abolished and revised to be as follows: *"For the power production facilities that conform to national planning, standards, or industrial standards, the electricity grid enterprises shall recognize their grid synchronization and provide relevant services."* In this way, the investment and electricity grid synchronization of opening and distributive power generation can be enhanced.

2) The business district system of power supply shall be revised, and the foundation, function, and border of the traditional power supply district shall be reconsidered and redefined to meet the requirements for multi-element power transaction subject, bidirectional power transaction mechanism, and new-type power development forms such as distributive power generation, microgrid, and energy Internet.

3) The laws for integration of power transmission and power distribution shall be revised to break the integration, to seek the possible space for separated investment and transaction of power transmission and power distribution, and to seek the independent investment, operation, accounting of power transmission and power distribution respectively.

4) The transaction and dispatch shall be separated and institutionalized to transform the power grid to the transmission channel and public service platform, and define the administration frame, organization frame, and regulatory system of the independent transaction and dispatch organizations.

5) The regulatory system of the power system shall be identified to reinforce the responsibilities and obligations of the relevant power supervision organizations to reinforce the law-based administration and supervision abilities.

16 Renewable Energy Supporting Policies

16.1 Evaluation on key mechanisms of renewable energy development

China has proposed the energy development direction for revolutionizing energy production and consumption. Continuously increasing the supply of clean and green energy, as well as improving its proportion in energy production and consumption is the basis for energy revolution. The national target is to increase the proportion of non-fossil energy in the energy consumption up to 15% and 20% respectively in 2020 and 2030. It guides the future energy transformation and specifies the tasks of near and medium term renewable energy development.

In the 13th Five Year Plan for the development of renewable energy, four key safeguard measures are proposed, including establishing a target-oriented management system for renewable energy development and utilization; implementing the full-amount guaranteed purchase mechanism for renewable energy power generation; establishing the green certificate trading mechanism for renewable energy; and strengthening supervision over renewable energy.

Besides, in 2015, China first tested several bidding programs regarding advanced technologies in the field of large PV, in 2016 all PV projects except those concerning poverty alleviation projects were available for bidding. In early 2017, China started to rapidly promote clean energy (renewable energy included) heating. The implementation of these policies reflects the policy innovations in achieving total amount objective, strengthening system operation management, advancing renewable energy technology, reducing cost, and expanding the sources for renewable energy subsidies, Furthermore, these policies are critical systematic arrangements in determining whether or not renewable energy can develop sustainably and healthily in the future. The implementation of above mentioned key mechanisms and policies in 2016-2017 is analyzed as below.

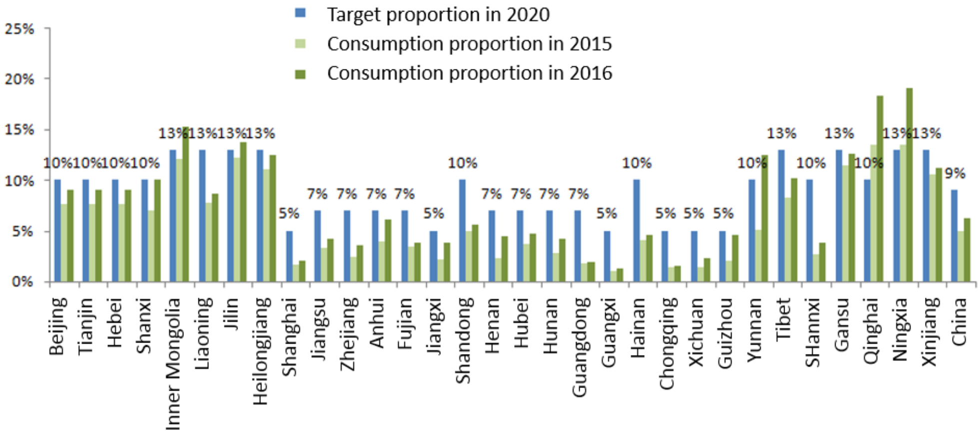
Establishment of orientation mechanism for renewable energy to guarantee the realization of energy transition

In February 2016, the National Energy Administration (NEA) issued the Guidelines Regarding the Establishment of Orientation Mechanism for the Development and Utilization of Renewable Energy (GNXN [2016] No. 54) to specify the establishment of the orientation mechanism. Its core is to tailor the target proportion of renewable energy consumption in the total primary energy consumption in every province (and/or district, city) in accordance with its distinctive renewable energy resources status and the energy consumption level. It also specifies the proportion of renewable energy power in the primary power consumption in the whole society. The target proportions will be allotted annually, and exploitation and utilization of the renewable energy will be monitored annually in provincial government, grid companies and power generation enterprises.

As a measure to carry out and supervise Orientation Mechanism, NEA issued the 2015 Report of Annual Supervision and Evaluation on National Renewable Power Development in August 2016 and issued the 2016 Report in April 2017. In the Report of 2016, in addition to the consumption of total renewable energy power and non-hydro power in all provinces (regions and municipalities), it also addressed the protective takeover of wind power and PV; renewable energy delivery by extra-high voltage lines; and the situation in some demonstrative provinces and regions for national clean energy.

According to the Report, in 2016, the proportion of non-hydro power renewable energy consumption of Qinghai, Ningxia, Yunnan, Inner Mongolia, Jilin and Shanxi provinces achieved the 2020 objective, that of Guizhou, Gansu, Heilongjiang, Anhui, Beijing-Tianjin-Hebei Region and Jiangxi was close to the objective, but that of Shaanxi, Hainan, Guangdong, Liaoning and Shandong was far from it.

Figure 16-1 Proportion Objective of Non-Hydro Power Renewable Energy Consumption in 2020 and Consumption Proportion in 2015 and 2016



(Data source: Government documents from the National Energy Administration)

In order to further activate the Orientation Mechanism, detailed supporting work in the following aspects is required: Firstly, to specify the responsibility subjects for the target tasks and to distribute the annual goal; secondly, to enhance binding management measures. For enterprises and regions not achieving the objectives, corresponding measures will be detailed in order to enforce and drive them; thirdly, to intensively study and perfect the design of the green certificate system. In addition, the trading mode, trading price, organization management and other related issues involved in the green certificate trading mechanism should be taken into systematic consideration; Finally, to combine the policy regarding development and utilization goals with the policy regarding current prices, subsidies, etc. Once the new mechanism is established, significant adjustments are required to be made to the current power price policy and subsidy mode. Furthermore, it should be given full consideration to connecting the new mechanism with such relevant mechanisms and policies as the current price, subsidy, Emission Trading System (ETS), finance & tax, and full-amount guaranteed purchase mechanism.

The role of policy implementation in carrying out the full-amount guaranteed purchase mechanism for renewable energy

The Orientation Mechanism can help renewable energy power to develop and grow in the future. However, apart from the renewable energy power consumption, problems in implementing the benchmark power price policy of renewable energy start to emerge in recent years. In particular, after the publishing of the power system reform plan in 2015, some provinces and regions gave away renewable power like wind power and solar power in the name of power marketization pilot, exacerbating electricity rationing. For example, in Gansu province, electricity generators signed low-price power supply agreements with large consumers regarding renewable power like wind power and solar power. In Northeast China fossil-fuel power generation rights took the place of renewable power generation rights. Besides, for grid-connected consumption of renewable energy power in Xinjiang and Yunnan, though the quantity is guaranteed, the price is not guaranteed. Under this circumstance, the National Development and Reform Commission (NDRC) issued the Regulations for Full-amount Guaranteed Purchase of Renewable Energy Power Generation (FGNY [2016] No. 625) in March 2016, which focused on the following key contents:

- According to the benchmark price of grid-connected electricity and the utilization hours, both appointed by the States, the grid enterprises shall give consideration to the market competition mechanism. Through implementing preferred electricity generation system, they have to purchase all the allotted grid-connected electricity in the Renewable Energy Power Generation Project;
- the annual generating capacity is divided into mandatorily purchased power and market trading power, both of which have the preferred generation right;
- the State checks and publishes the annual utilization hours for mandatorily purchased electricity, which is generated by various renewable resources and under various Renewable Energy Grid-connected Power Generation Projects;
- Within the quota of mandatorily purchased power, if renewable energy generation is limited due to power network dispatching, then the preferred generation rights or preferred generation contracts shall automatically be transferred to less preferred units within the same system. The corresponding unit is responsible for compensating to the Renewable Energy Grid-connected Power Generation Project. Within the quota of mandatorily purchased power, the preferred generation right for renewable energy cannot be positively transferred through market transaction.

The full-amount guaranteed purchase mechanism for renewable energy power generation alleviates and solves the problems of non-technical power rationing of wind power and PV.More importantly, for regions with power rationing caused by non-technical reasons it safeguards the executive effect of the benchmark power price policy within the minimum

Full-amount Guaranteed Purchase of utilization hours.In addition, with the reforming process of current power system, more power than the minimum Full-amount Guaranteed Purchase required will enter the power market, which lays the foundation for giving renewable energy full access to power market after it gains its competitiveness.

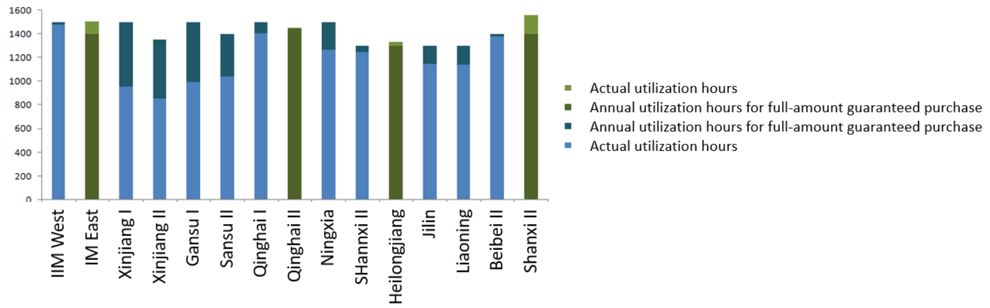
In May 2016, NDRC and NEA issued the Notice on Management of Full-amount Guaranteed Purchase of Wind Power and PV (FGNY [2016] No. 1150), approving the annual utilization hours for minimum guaranteed purchase in major wind power and large PV regions. In 2016, only Liaoning, Hebei and Shanxi provinces met the requirement for the annual utilization hours for minimum guaranteed purchase of wind power; similarly, only East Inner Mongolia, Shanxi and Heilongjiang provinces met the requirement for the annual utilization hours for minimum guaranteed purchase of PV. Therefore, it is necessary to continue intensifying the executive effect of the policies.

As seen from specific data analysis, the full-amount guaranteed purchase policy has started to take effect. In 2016, the wind power curtailment in China was 49.7TWh, and the proportion of four seasons in the annual wind power curtailment was respectively 39%, 27%, 14% and 20%. The proportion of wind curtailment in main wind curtailment regions dropped significantly after the issuance of the policy. According to preliminary statistics from China National Renewable Energy Centre, in the first quarter of 2017, the wind curtailment was 13.5TWh and the PV curtailment was 2.3TWh, which decreased by 30% and 23% respectively compared to the same period last year; the wind power curtailment in China in the first half year was 23.7TWh, with a year-on-year decrease of 27%; PV curtailment was 3.7TWh, which was the same as last year. It should be noted that the wind curtailment and PV curtailment decreased under the condition that the newly increased installed capacity of wind power and PV in 2016 respectively reached 19.3GW and 34.54GW. Therefore, significant decrease can be seen from the rate of wind curtailment and PV curtailment. In the first half of the year, the wind curtailment rate in China was 14%, with a year-on-year decrease of 7%, and PV curtailment rate in China was 6.7%, with a year-on-year decrease of 4.5%.

In terms of implementation, it is suggested to refine the full-amount guaranteed purchase mechanism and intensify its execution in the following aspects:

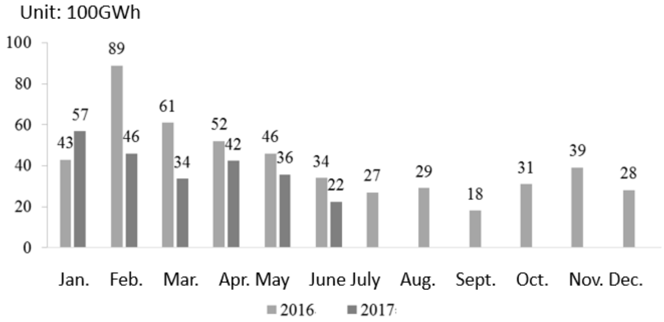
- To overall coordinate the full-amount guaranteed purchase of renewable energy and all kinds of existing trading in some parts of the nation;
- To adjust and implement the full-amount guaranteed purchase mechanism according to the power system reform process as well as changes in external environment. Now that the economic downturn is still severe, and the supply still exceeds demand in power sector, in order to reduce the dampening effect caused by local policies which are against renewable energy consumption, one of the solutions can be implementing the full-amount guaranteed purchase mechanism.

Figure16-2 Annual Utilization Hours for Full-amount Guaranteed Purchase of PV and Actual Generation in 2016



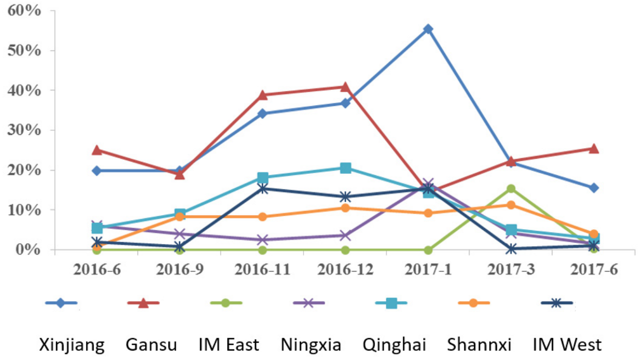
(Data source: Government documents from the National Energy Administration)

Figure 16-3 Wind Curtailment quantity in China in 2016 and 2017



(Data source: Renewable Energy Power Information Bulletin, Issue 7th, 2017, CNREC)

Figure 16-4 Proportion of PV Curtailment in Some Provinces from June 2016 - June 2017



(Data source: Renewable Energy Power Information Bulletin, Issue 7th, 2017, CNREC)

Promote establishing voluntary and mandatory markets of green certificate to solve problems of subsidy shortage of curtailment

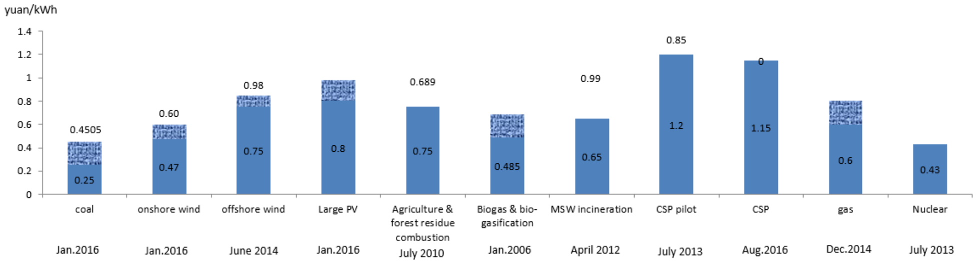
The problems of renewable energy subsidy and wind and PV curtailment are two key factors influencing current renewable energy development, where the problem of subsidy default has affected the whole renewable energy industry chain from downstream markets to upstream manufacturing enterprises. In terms of subsidy default, there are two major problems. Firstly, power generation projects' subsidy qualification is delayed; secondly, subsidy capital allocation is delayed. Essentially, the root cause for these two problems is the gap between the Renewable Energy Fund and the renewable energy power price subsidy capital. According to the statistics from the Ministry of Finance (MoF), the accumulative gap was approximately RMB 52 billion as at the end of 2016. If sticking to the installed capacity, the amount of electricity and the target cost of various renewable energy resources illustrated in the 13th Five Year Plan for the development of renewable energy, and assuming the additional criteria of the current renewable energy power price is still RMB19/MWh, the coal power benchmark price is still the same, then the gap of power price subsidy capital in 2020 will be about RMB 60 billion, and the total gap will reach RMB 244.3 billion In addition, even if all the required renewable energy surcharge can be collected, the total gap will reach RMB 203.9 billion. This result is estimated based on the 2015 rate of renewable energy surcharge, not including other subsidy needs than wind power, PV and biomass power generation. Furthermore, If the installed capacity of renewable energy significantly exceeds the expected scale (for example, the installed capacity of PV generation in the first half of 2017has been already close to the development objective in 2020), then the demand for subsidy will rise even more. Therefore, it is urgent to expand the scale and channels of renewable energy subsidy capital. It is suggested that the MoF arrange funds to solve the existing gap in power price subsidy one year after another. The increased part can be solved by adjusting the additional fund level of renewable energy power price and promoting green power certificate trading system as soon as possible.

In January 2017, NDRC, MoF and NEA issued the Notice on Trial Implementation of Renewable Energy Green Power Certificate Issuance and Voluntary Trading System (FGNY [2017] No. 132), by which the renewable power voluntary green certificate trading would be started on July 1, 2017, and the power quota assessment and mandatory trading of green certificate will be started in due time from 2018. As an important market, voluntary green certificate can greatly help disseminate the concept of green power consumption. It is also helpful in establishing a mandatory market. In near term, however, though the scale of voluntary market is expected to grow fast, its effect on solving the problem of power price subsidy capital gap is very limited. Therefore, in order to meet the realistic demand in China, it is necessary to launch and implement the mechanism for mandatory constrained trading of quota and green certificate. The quota subject may be selected from power generation enterprises and power selling (grid) enterprises.

Adjust and transform renewable power pricing mechanism to encourage renewable power to enter the market gradually

In 2006, China established the Feed-in-Tariff (FIT) and expense compensation mechanism for supporting renewable energy power development. After that, it successively issued the feed-in benchmark price of onshore wind power, large PV, biomass power generation, offshore wind power and Concentrating Solar Power (CSP), as well as per-kWh subsidy policy for distributed PV. According to the development situation of various renewable energy technologies, the government will make corresponding adjustment. For example, the benchmark power price level of onshore wind power and large PV has been reduced several times since 2014. The current benchmark power prices of renewable energy and coal power only reflect the direct costs of various power sources and take no account of the external costs of fossil energy in resources, environment and ecology, or the external benefits of renewable energy. Although the costs of wind, PV and other renewable energy sources have declined greatly in recent years, both their direct apparent costs and the benchmark power price level are much higher than those of coal power, which greatly reduces the affordability and competitiveness of renewable energy. It is also one of the main causes for soaring demand for renewable energy power price subsidy capital.

Figure 16-5 Benchmark Power Price Level of Main Power Sources in 2017



(Data source: Government documents from the National Development and Reform Commission)

In 2015, Chinese Government activated and implemented a new round of power sector reform. One focus of this reform is to promote power pricing reform, including following content: transmission and distribution of electricity should be independent; check the exclusive power price; non-commonwealth selling price should be dominated by market; encourage the plan reform of power generation and utilization; the trading of power should gradually turn to market (selling for direct trading, long term trading and trans-regional trading); and form a price suitable for marketized trading.

The power system reform has new requirements for innovation in power price subsidy mechanism of renewable energy. According to the reform direction, renewable energy should all enter the power market in the future. On the one hand, the renewable energy price formation mechanism can be adjusted and transformed according to the objective of marketization, and on the other hand, it can be a demonstration for power price reform.

With gradual promotion of power market reform, in the future, the marketized power pricing mechanism will be realized, a fair, open and flexible power market scheduling mechanism will be established, and the subsidy pattern based on the benchmark power prices of renewable energy and coal (i.e. to subsidies the difference between RE FIT and coal power benchmark price), will be gradually transformed into the pattern based on renewable energy market pricing. Detail suggestions are shown as follows:

- Implement the renewable energy Feed-in-Premium (FIP) mechanism in order to keep in pace with the power system reform process. Namely, adjust the current policy of "coal power benchmark price + deficiency compared to RE FIT" to the policy of "coal power benchmark price/market power price + FIP for premium". It is also required to establish the regular assessment on FIP standard and a mechanism that can be adjusted according to the changes in development situation,the cost of renewable energy and the changes in power market price;
- Apply differentiated power price policy to renewable energy technology at different development stages. With respect to renewable energy with mature technology and scale development, such as onshore wind power and PV, it is proper to implement FIP in the first phases, and shorten the adjusting period of power price or subsidy level; with respect to advanced renewable energy power generation at demonstration and promotion stage, it is suggested to maintain stable economic policies, implement benchmark power price mechanism, provide a relatively stable investment environment and promote its commercialized development process;
- Gradually promote the implementation of power price bidding policy. China has started the exploration on determining developers and power price of renewable energy through competition. China implemented competitive comparison and selection for CSP, and started bidding for Advanced PV Technology Base projects and normal PV projects since 2016. As seen from the implementation effect, the competitive comparison and selection for CSPbasically reached the objective of discovering the price demand, and the bidding for AdvancedTechnology PV Base had a remarkable effect on reducing power price. As seen from the long-term effect, competitive bidding not only follows the international development trend, but also promotes technological progress and industrial upgrading of renewable energy, which is beneficial to sustainable and sound development of renewable energy industry in China. Additionally, another advantage of bidding price mechanism is that it matches with various power price mechanisms, which leads to fixed bid power price and bidding with fixed subsidies. Therefore, bidding price mechanism may be implemented in parallel with existing FIT policies, FIP policies which will be gradually transformed in the future, and various economic incentive policies where green certificate trading is considered.

Take advantage of the substitution function of renewable energy heating, expanding the application scope and scale

In addition to power, heating is another important form of utilizing renewable energy. Internationally, countries leading in renewable energy development basically develop technologies and their application of renewable energy power and heating simultaneously. In some countries and regions, renewable energy has become a main energy source of heating system. For example, in Iceland and Sweden, renewable energy heating has taken up over 60% of their terminal heat demand. In 2015, modern renewable energy heating and refrigeration took up approximately 8% of the global terminal heating and refrigeration energy consumption, while the heating and refrigeration energy consumption took up approximately 50% of the global terminal energy consumption, which shows that renewable energy heating has played an important role in energy supply.

For China, the urgency and practical significance of continuously expanding application of renewable energy heating are mainly reflected in two aspects.

On one hand, it is very important for achieving the proportion objectives of non-fossil energy in primary energy consumption in 2020 and 2030, especially for achieving energy supply and consumption transformation. In the current energy consumption of China, the proportion of general heating is still higher than that of power, transportation and raw materials. If a cleaner supply and consumption in heating cannot be realized, even though the proportion of power cleaning is very high, as the proportion of power in overall energy consumption is fixed, the speed and space of energy transformation will still be slowed down.

On the other hand, heating by renewable energy means other energy sources are substituted. This can solve regional environmental problems. Recently, in northern regions of China in winter, the demand of civil heating and industrial energy consumption for coal combined led to prevalent air pollutions like haze frequently taking place in a great number of regions. Renewable energy heating can make contributions to regional environmental management to some degree.

Renewable energy heating is diversified in aspects of source, technological means and product type. Currently, main technologies are at their mature stage. For example, solar heating and geothermal energy can be utilized directly; ground source heat pump can satisfy all kinds of heating and cooling demands, such as hot water, heating, steaming and refrigeration; and biomass energy heating can provide combined heat and power, heating, steam, solid formed particle, bio-natural gas and other energy products by taking agricultural and forest residues, municipal wastes, factory organic wastewater and wastes as raw materials. Apart from that, in northern regions, where renewable energy resources are abundant, heating demand is large and power supply is relatively redundant, clean power heating can also be developed so that one day they may replace coal-fired heating by small boilers. In 2015, the scale of renewable energy heating utilization in China reached 67.5 million tce.This was 116% of the wind power contribution in that year. However, renewable energy heating is non-commercialized energy and has not been incorporated into the national energy statistical system currently, so its role in the energy structure adjustment is usually ignored, and the "preference of power to heating" is a common scene. Therefore, it is necessary to accelerate the establishment of national heating metering and statistical system, incorporating renewable energy heating into the national energy statistical system.

In the first quarter of 2017, several departments of the central government carried out intensive researches on clean energy heating in northern regions. Hopefully, renewable energy heating is expected to achieve systematic breakthroughs in aspects of policies and mechanism. According to the 13th Five Year Plan for the development of renewable energy, renewable energy heating demonstration project for large-scale application will be carried out by sticking to the principles of "preferred utilization, economy and efficiency, multi-energy complementation and integration". Renewable energy heating is an important part of regional energy planning and should be well connected with urban development planning. It is necessary to promote renewable energy heating in architectural and industrial fields; launch the project that substitutes urban fuels with biomass; and accelerate the substitution of fossil energy with various renewable energy sources in heating field. It is also necessary to overall plan, construct and retrofit infrastructure for heat supply; strengthen the construction and reform of supporting grid; optimize the design of heating pipe network; and establish a comprehensive heat energy supply system with collaboration, complementation and gradient utilization between renewable energy and traditional energy. Various kinds of renewable energy heating and civil fuel can substitute fossil energy by approximately 150 million metric tons of standard coal equivalent in total by 2020.

It is suggested to collaboratively drive the development of renewable energy heating from both energy supply and demand sides. On the supply side, the focuses are as follows:

- improve the technical level and system reliability of renewable energy heating;
- accelerate the system integration capability of renewable energy heating, specifying the development ideas and way of thinking for integration between renewable energy and fossil energy heating, integration between power system and heat system, as well as a gradient utilization of energy;
- integrate Internet +, intelligent system control and optimized scheduling;
- By giving full play to different quality and cost advantages of different heating sources, reduce heating cost and improve overall heating efficiency.
- On the demand side, the focuses are as follows:
- stimulate the market demand for renewable energy heating with new mechanisms and policies. For example, build the comprehensive incentive policy mechanism including heat pricing and compensation policy, pipe network construction compensation policy, as well as tax and financial policies;
- establish various business models to promote large-scale application of renewable energy heating;

- the application scale and scope can be expanded by energy contract management, PPP, BOT , OT and etc.;
- promote the construction of regional energy stations.

16.2 Renewable energy support mechanisms: international trends and experiences

The transition of an energy system based on conventional energies like coal, gas and nuclear to one that more and more relies on renewable energies requires the political will to create an environment in which renewable energies can thrive. The following chapter gives an overview of different policy approaches to support the development of renewable energies and their integration into the energy system. It provides insights into the most commonly used mechanisms – ranging from obligatory quota systems to feed-in tariff (FIT) and feed-in premiums (FIP) – and presents relevant international case studies to illustrate trends and experiences made around the world. The case studies were chosen based on their relevance for the challenges that are currently occurring in China.

Renewable portfolio standards (RPS) / quotas

Concept

By defining a renewable portfolio standard (RPS) or renewable energy quota, a state sets a clear target for the share of renewable energy in the energy mix of a defined entity, e.g. power utilities, energy suppliers or large energy consumers. As a measure of enforcement, entities that do not fulfil the required quota usually have to pay a fine. The fine has to be set high enough to incentivise regulated entities to increase their share of renewable energies to the required level. If the fines are higher than the costs for increasing the entity's RE share, chances are high that they will fulfil their quota obligations so that the overall targets for RE share in the energy system can be met.

The quotas are set either by national, regional or local governments and vary in their specific requirements. In order to allow for a continuous supervision of the progress made the quota targets may be adjusted over time. The state usually does not define how such targets should be met by the respective entity, though. In many cases the quota system is combined with the introduction of renewable energy certificates or green electricity certificates. The cap that a quota system sets on the desired volume of RE electricity can also have a limiting effect on the market development. When the quota is reached, further increase of RE energy production would lead to a decrease of green electricity certificate prices and thus reduce or eliminate the incentive for further expansion.

While clear targets set for the development of renewable energies generally increase the security of investments, the uncertainty of green electricity certificate prices may in turn increase investment risks.

Case Study: United Kingdom (UK) – quota and certificate system

The Renewables Obligation (RO) came into effect in 2002 in England, Wales and Scotland, followed by Northern Ireland in 2005. Itis one of the UK's main support schemes for large-scale RE projects. On 31 March 2017, the RO was closed to all new generating capacity and was replaced by the Contract for Difference (CfD) programme.

Table 16-1 Yearly obligation levels (ROCs per MWh) and buy-out price[63]

	2010/ 2011	2011/ 2012	2012/ 2013	2013/ 2014	2014/ 2015	2015/ 2016	2016/ 2017	2017/ 2018
England, Wales, Scotland	11.1%	12.4%	15.8%	20.6%	24.4%	29.0%	34.8%	40.9%
Northern Ireland	4.3%	5.5%	8.1%	9.7%	10.7%	11.9%	14.2%	16.7%
Buy-out price	£36.99	£38.69	£40.71	£42.02	£43.30	£44.33	£44.77	£45.58

Criticism and transition

In 2007, Ofgem published a press release64 in which it claims that the RO scheme "is a very expensive way of reducing carbon emissions compared to other alternatives". With about £184-481 (about US-$242-632) the cost per ton of greenhouse gas emissions saved under the RO were estimated to be much higher than the costs of other policy measures such as the EU Emissions Trading Scheme (ETS) at £12-70 (about US-$16-92) a ton. Current price levels of the ETS are even lower, with prices of about £3.4-5.1 (€4-6.5) per tonne since February 2016.

Of gem also criticized the failing link of the level of support to the price of electricity or the price of carbon emission allowances under the ETS. It claims that therefore "existing and future renewable generators will benefit, at customers' expense, from much higher electricity prices". The Contract for Difference (CfD) programme aims at addressing these shortcomings.

Evolving feed-in tariffs (FIT) to feed-in premiums (FIP)

The main assumption of an FIT scheme is that renewable energy projects by themselves are not competitive so that a market for these technologies would not develop by itself. By guaranteeing fixed revenue over (most of) its lifetime, the risk profile of an investment in RE and thus the financing costs are supposed to be minimised. The level of FIT is usually determined ex ante, based on the expected costs of an RE plant (capital costs, O&M, fuel, financing) and taking into account a certain return on the investment. Many FIT schemes

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63https://www.ofgem.gov.uk/publications-and-updates/renewables-obligation-ro-buy-out-price-and-mutualisation-ceilings-2017-18

64https://www.ofgem.gov.uk/ofgem-publications/76523/16662-r5pdf include a degression mechanism that decreases the support for new RE plants over the years in order to push market integration.

Risks of FIT and Transition from FIT to FIP

Due to information asymmetry between political regulation and market development it is difficult to set the degression at the right level so that too high or too low FITs are avoided. Generally, there is a risk of overcompensation. Another weakness of FIT schemes is that while there is much incentive to maximise the energy production from RE, there is little to no incentive for RE plant operators to respond to price signals.

One way to respond to this weakness is to switch from feed-in tariff to feed-in premium (FIP). Precondition for this measure is the existence of functional market structures for electricity. Just like for FITs, FIPs can be differentiated according to both size and location of the renewable energy project and the applied technologies. There are different design options: One option is to have a fixed FIP that is independent of the market price. In order to avoid overcompensation, maximum and minimum FIP-levels (cap and floor price) can be introduced. This measure leads to an "expectation corridor" for revenues and payment obligations for the RE plant operator and the regulator respectively. The alternative is a sliding or floating FIP that varies depending on the market price. By this, a stable level of compensation can be reached. Sliding FIPs can be centrally pre-determined, and also be set by an auction or tender scheme.

Case Study: Germany offshore wind

In Germany, during the past 13 years RE have been supported primarily by a set feed-in tariff (FIT). In 2015, due to the technological development of RE, their cost reduction and successful step-by-step market integration, the support scheme was adjusted to FIPs for RE plants bigger than 100kW. For offshore wind plants, the FIT scheme remains applicable to all plants commissioned before 2021 because of the long-term planning cycles.

Background and support policy of offshore wind

With its energy concept 2010, the German government set the goal to reach a total installed offshore wind capacity of 15GW by 2030. Under the new FIP scheme for offshore wind energy projects two phases are distinguished[65]:

- Transition phase (project commissioning between 2021 and 2025): FIP scheme based on tenders open only for existing offshore wind projects that already are at an advanced stage or approved and that will be put into operation after 31 December 2020. The yearly overall capacity for the tenders in 2017 and 2018 is set at 1,500MW with specific network connection capacities for different clusters in the North and Baltic Sea as restriction/limiting element.
- Central model (project commissioning as of 2026): FIP scheme based on tenders open for new offshore wind projects with an overall yearly capacity of 700-900MW.

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[65] https://www.gesetze-im-internet.de/windseeg/index.html#BJNR231000016BJNE001700000

An Area Development Plan defines the areas where offshore wind parks may be built. Only awarded projects may be built in these areas, may use network connection capacities and have the right to receive a market premium.

In both phases the general principle applied is a sealed, pay-as-bid auction. Tender participants are listed according to their bidding value. Projects are chosen until the yearly capacity is reached unless any other restriction, e.g. the network connection capacity, kicks in. The respective bidding values then constitute the so-called applied value for the awarded project. The FIP that is payed to the RE plant operator is determined by deducting the monthly average market price from the applied value. If the applied value is lower than the monthly average market price, no FIP is granted. The FIP is floating on a monthly basis with the level of the average market price.

First auction results

On 1 April 2017, the first tender for offshore wind projects in the transition phase was carried out by the German Federal Network Agency. The results of this first tender were surprising to most experts: While the maximum price beforehand was administratively set at 12 ct/kWh, the average capacity-weighted bidding value of the four projects that received the knock was only 0.44 ct/kWh. Three out of the four awarded projects even offered a bidding value of 0 ct/kWh. Only one awarded project offered a bidding value of 6 ct/kWh (see Table 16-2 2-2) provides an overview of the awarded projects.[66]

Table 16-2 Results of the first tender for offshore wind projects in Germany

Project	Owner	Completion	Capacity (MW)	Bidding value (EUR ct/kWh)
He Dreiht	EnBW	2025	900	0
OWP West	DONG	2024	240	0
Borkum Riffgrund West 2	DONG	2024	240	0
Gode Wind 3	DONG	2023	110	6

The fact that bidders were willing to go as low as 0 ct/kWh shows that costs for offshore wind projects have declined in the past years and have now reached a competitive level. The winning bidders argued that they were able to issue these zero-subsidy bids because wind turbines by 2024/2025 are expected to be much larger and more efficient than today, the increased operational lifetime of up to 30 years helps to improve the cost structure and cluster synergies with adjacent wind farms lead to reduced O&M costs. Furthermore, they argue that these bids are possible because the transmission to the shore is not included in the construction scope and thus in the bidding value.

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[66] https://www.bundesnetzagentur.de/SharedDocs/Pressemitteilungen/DE/2017/13042017_WindSeeG.html

Criticism of the results - too good to be true?

Some observers, however, criticised that the winning bidders (both large energy companies) may have undervalued their projects for strategic reasons. The underlying assumption is that the winning bidders are well-financed, established companies and could have deliberately placed an "unbeatable" bid in order to block the project volumes for smaller competitors. Due to the long lead time between the tender results and the planned date of commissioning, specialized companies that did not get awarded might get out of business in the meantime or reduce their exposure to the German market significantly. In addition, the winning bidders could prefer and afford to pay the penalty for non-construction (currently at 100€/kWp installed capacity) when they do not see the price/cost-structure develop sufficiently, since the penalty is relatively low in comparison to the overall financial project volume.

In any case, considering the substantial reduction of costs compared to expected scenarios, there are discussions ongoing that call for an increase or even complete removal of the limit of 15GW installed offshore wind capacity until 2030.

Auctions as part of different market designs

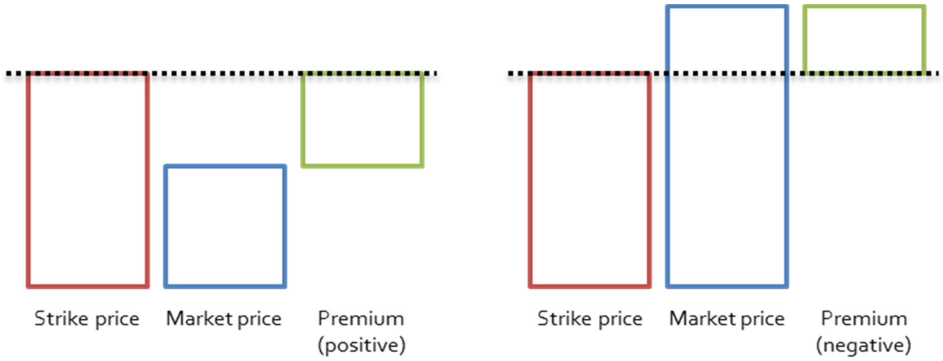
Trend towards auctions

Independent of differences within basic principles of the market design, auctions are a tool that is commonly used as steering mechanism within RE incentive schemes. It is quite usual in highly regulated energy markets that not only the RE incentive scheme, but also conventional capacities are awarded via auctions. Some countries continued with this approach when the started to introduce RE incentive policies, other countries started with a more open RE incentive design and gradually scale that back via implementing auction mechanisms as is illustrated in the case studies below. In any case, the specifics of the auction design, e.g. the requirements for project and bidder qualification, penalties for non-construction, required documents on the project maturity etc., have significant impact on whether the auctions will be successful and RE will be installed in a reliable and cost-efficient way.

United Kingdom (UK) – new auction scheme

On 31 March 2017, the Contract for Difference (CfD) replaced the Renewables Obligation (RO) as main support scheme for large-scale renewable electricity projects (more than 5MW). The CfD is a sliding FIP scheme based on the difference between the so-called "strike price", which is the result of a pay-as-clear (or uniform pricing) auction, and the average market price for electricity in the GB market. If the market price is higher than the strike price, renewable generators must pay back the difference between the market price and the strike price (see also Figure 2-6). CfD contracts are awarded for a period of 15 years.

Figure 16-6 Contract for Difference (CfD) in UK



RE plant operators who want to participate in the CfD scheme must participate in one of the yearly allocation rounds. These allocation rounds consist of three auction processes, one for each of the three budget pots (see also Table 16-3 3). Before the auction, technology-specific maximum strike prices, so called "Administrative Strike Prices" (ASP) are set. The bids are then listed in ascendant order of the price they offered. Bids will be considered consecutively until the yearly budget for new projects is exhausted, applying a sophisticated formula including multiple variables such as a technology base load factor. The project that is last accepted sets the strike price for that year for all other projects accepted (pay-as-clear auction). In the unlikely event that the budget is not exhausted because too few projects participated in the auction, all bids are offered the ASP.[67][68]

From the points of criticism and outlook, the auction process overcomes the problem of uncertainty of payback, however, it also introduces a new element of uncertainty compared to the former support scheme Renewables Obligation (RO). Due to the auction process there is now much more uncertainty over whether or not the support will be granted at all.

Table 16-3 Revised CfD budget per year for 2014 Allocation Round (in Million GBP)[69]

		2015/ 2016	2016/ 2017	2017/ 2018	2018/ 2019	2019/ 2020	2020/ 2021
Pot 1	Onshore wind (>5MW), Solar PV (>5MW), Energy	50	65	65	65	65	65

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[67] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/601120/Allocation_Framework_for_the_second_Allocation_Round.pdf

[68] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/611613/CFD_FAQ_document_for_28_April_2017.pdf

[69] https://www.gov.uk/government/collections/electricity-market-reform-contracts-for-difference#cfd-budget-and-allocation.

established technologies	from Waste with CHP, Hydro (>5MW and <50MW), Landfill Gas and Sewage Gas						
Pot 2 **less established technologies**	Offshore Wind, Wave, Tidal Stream, Advanced Conversion, Anaerobic Digestion, Dedicated biomass with CHP, Geothermal	0	155	260	260	260	260
Pot 3[70]	biomass conversion	0	0	0	0	0	0

Case Study: Mexico auction scheme

Clean energy as defined in Mexico, is renewable energy, nuclear, efficient industrial cogeneration, and fossil generation linked to carbon capture and storage (CCS). The goals for clean energy in electricity generation are 25% in 2018, 35% in 2024 and 50% in 2050.In 2015 the share of clean energy was 15% and the share variable renewable resources were 2.5%, mainly wind. In August 2014, a fundamental transformation of Mexico's energy sector was initiated. By partially unbundling the Comisión Federal de Electricidad (CFE), the state-owned power company that formerly had a monopoly on power production and power supply, new private actors from Mexico and abroad were allowed to participate in Mexico's power market as competitors. Renewable generators are now able to sell the electricity they produce on the sport market. Coming from a fully regulated, non-market-based system, reforms since then paved the way for the creation of a wholesale power market linked with auction mechanisms and accompanied by a Clean Energy Certificate (CLE) scheme.

Beside the Clean Energy Certificate (CEC) scheme (see detailed description in chapter3.4), the main tool applied is that of medium-term capacity auctions (3-year period) and long-term capacity and energy auctions (15-year period) which are held at least once a year.

The general idea of long-term auctions is to provide some certainty for future revenues and thus to reduce risk and ultimately capital costs particularly for renewable energies. There are two forms of long-term auctions in Mexico: capacity auctions and energy auctions. Via

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[70] For Pot 3 there is no budget released in this allocation round but this does not preclude budget being allocated to this pot in future rounds.

capacity auctions projects gain the right to receive grid connection for a certain amount of capacity at a specific grid node and to thus to trade their electricity on the central spot market. Capacity auctions are technology-neutral so that both conventional and renewable energy projects can participate.

There are two different price calculation methods within the energy auction depending on whether the respective energy technology is defined as "baseload clean energy" or "intermittent clean energy".

Baseload clean energy is defined as nuclear, hydropower, biomass, geothermal and efficient cogeneration. The applied price finding mechanism ranks the offers according to their bidding price per MWh. To some extent, baseload clean energy is comparable to conventional power plants, so the feed-in characteristics and available full-load hours are high and well predictable.

The price calculation for intermittent clean energy which captures wind and solar installations is more complex. In order to address grid requirements with regard to time and location and maximum power that is fed in, the price determination is based on a set of variable price benchmarks that are defined for each grid node by the National Centre for Energy Control (CENACE)[71]. The node specific benchmarks are set for the duration of the contract (15 years) and include variations for daily/seasonal/yearly differences. For future energy auctions benchmarks can be adjusted. For intermittent clean energy, the final energy price depends on three factors: the value of the bid according to the contract and both the (variable) benchmark and the (fixed) so-called "expected average marginal price", i.e. the marginal cost of electricity production. When the benchmark value at a given time exceeds the expected average marginal price, the RE plant operator receives the value of the bid plus the benchmark value. On the other hand, if the benchmark at another given time is lower than the expected average marginal price, the RE plant operator receives the value of the bid minus the benchmark value.

Since the set of benchmark values is known in advance, the variation of revenues will be considered by the RE plant operators when defining their bidding values. Projects with low marginal costs that feed into grid nodes with higher benchmark prices and projects that are capable of delivering power at peak times are rewarded.

In 2016, the first two rounds of long-term auctions were held. The first auction round in March 2016 included capacity auctions for 500 MW installed capacity and energy auctions for a total of 6.46 TWh/year, followed by a second one in September 2016, with energy auctions for 8.9 TWh/year and capacity auctions for almost 1.2 GW.[72] Overall, long-term contracts for around 4.9 GW of new capacity have been awarded to private investors (including several global players) in 2016. Solar PV and wind energy, both falling under the price calculation method for intermittent clean energy, accounted for almost all the energy

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[71] https://www.gob.mx/cenace

[72] https://www.gob.mx/sener/prensa/con-precios-altamente-competitivos-se-anuncian-los-resultados-preliminares-de-la-2-subasta-electrica-de-largo-plazo?idiom=es

contracts awarded[73] which is striking since the support scheme is technology-neutral among "clean energy technologies". While in the first auction an average price of about 47 US-$/MWh was reached, the second auction attracted even more market participants and lowered the price level by 30% to 33 US-$/MWh.

Green electricity certificates for renewable power

Background: Role and functionality of green certificate trading

GEC are tradable assets which prove that electricity has been generated by a renewable energy source, and can be sold separately from the commodity electricity. Hence the energy producer receives the price of electricity and can create extra revenue by selling the GEC. One certificate is typically issued per 1 MWh of renewable electricity produced. Renewable electricity supported by FIT and FIP do not qualify for green certificate trading and are excluded from the market.[74]

Once renewable energy is fed into the grid, it is physically impossible to separate from electricity generated by other sources. However, the demand for electricity solely from renewable sources exists and is increasing. With the use of GEC the need for renewable electricity can be met because with the certificates it is possible to decouple physical supply of electricity from its green characteristic. This means that the supply of electricity is separated from the fact that it is "green" electricity. The certificates are traded in parallel to the electricity. There are two main mechanisms for markets for green electricity certificates; Mandatory Markets and Voluntary Markets.

European Market for Guarantees of Origin

Background of GOs

In Europe, green electricity certificates are called Guarantees of Origins (GOs). They are recognized in all EU Member States plus Norway and Switzerland. They are traded bilateral between renewable energy producers and electricity buyers. This is done separately from the trade of electricity. Within this system, the GO and thus the green attribute of electricity, is sold across borders. There are less restrictions to the trade of GOs than to the trade of electricity, so the European market integration is much further advanced here. All GOs provide information on the energy source, technology used and data about the power plant.[75]

The market for green electricity certificates was established in 2002. The EU guideline 2009/28/EC requires that all European Member Stats have to establish a national registry for GOs. A joint standard named European Energy Certificate System (EECS) was

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[73] http://www.iea.org/publications/freepublications/publication/MexicoEnergyOutlook.pdf

[74] European Energy Exchange AG (2017), EU-Richtlinie 2009/28/EG on trading certificates, retrieved from

https://www.eex.com/de/goo

[75] European Energy Exchange AG (2017), EU-Richtlinie 2009/28/EG on trading certificates, retrieved from
https://www.eex.com/de/goo

established and is managed by the association of issuing bodies (AIB). The AIB is a membership organizations consisting of national GO issuers. In 2016, there were 20 countries with an active AIB membership compliant with the EECS and using the AIB hub actively. However, there are still countries that are not connected to the AIB hub and either do not have any GO system or have established their own system. Table 2-4 provides an overview of the different status situations and countries. [76]

Table 16-4 Countries with EECS System in Europe[77]

Countries with European Certification System for GOs		
Austria	Finland	Luxembourg
Belgium	France	Norway
Croatia	Netherland	Slovenia
Cyprus	Germany	Spain
Czech Republic	Iceland	Sweden
Denmark	Ireland	Switzerland
Estonia	Italy	
Countries with national GO system – not integrated in the Association of Issuing Bodies		
Bulgaria	Greece	Hungary
Latvia	Lithuania	Poland
Romania	United Kingdom	
Countries only with GO legislation – no system		
Malta	Portugal	Slovakia
Other countries with interest in joining Association of Issuing Bodies		
Serbia		

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[76] Tom Lindberg (2016). White Paper: Building a larger and more robust marketplace for tracked and documented renewable power in Europe. ECOHZ. Retrieved from: https://www.ecohz.com/wp-content/uploads/2016/12/White-paper-building-a-larger-GO-marketplace.pdf

[77] Tom Lindberg (2016). White Paper: Building a larger and more robust marketplace for tracked and documented renewable power in Europe. ECOHZ. Retrieved from:https://www.ecohz.com/wp-content/uploads/2016/12/White-paper-building-a-larger-GO-marketplace.pdf

Market mechanism and functionality of GOs

GOs issuance, transfer and retirement are tracked via each AIB member national registry. The issuing bodies for the certificates are required to file documentation related to each transaction. If the electricity customer buys GOs, as documentation for the electricity delivered or consumed, the GOs are cancelled in the certificate registry. With the cancellation in the certificate registry double counting of electricity is prevented. GOs have a lifetime of 12 months after production, so the issued GOs must be traded and cancelled within 12 months. If they are not used after this period of time they expire and they are withdrawn from the market.

The GO system in Europe is only for disclosure purpose and represents a voluntary market. Some European countries have implemented mandatory markets with quota obligations. This must be fulfilled with individual certification schemes (see subchapter "Mandatory market in Norway and Sweden"). GOs cannot be used to regulate certain quotas for certain electricity consumers.

Before January 2017 GOs were traded at one common market place provided by the European Energy Exchange (EEX). Since January 2017 trade is only done bilateral between RE producers and RE buyers.

Market Participants and Volume

The market has reached a total 550 TWh of traded GOs in 2015 including national systems and the joined EECS system. The total volume related to the EECS GOs was the largest share; amounting more than 340 TWh. Total RE electricity production in Europe has surpassed 1100 TWh in 2015.[78] The volume excluded from entering the market was approximately 210 TWh in 2015. The excluded RE production was supported by other incentive schemes like FIT and FIP. Hydro dominates the market with more than 80% of the GOs volumes. The volume of Bio and Wind is around 50 TWh. Norway is the leading country supplying GOs. The country provided approximately 130 TWh from hydro. The following graphic provides an overview of the supply structure.[79]

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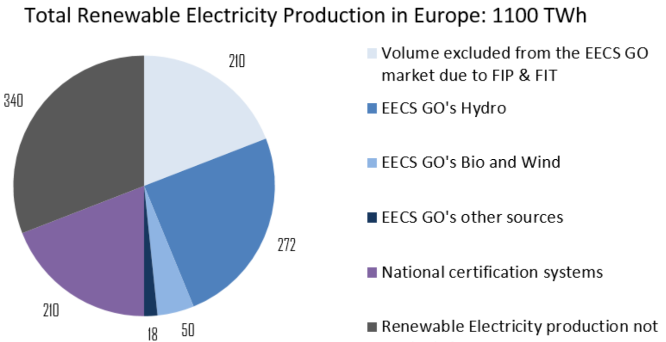
[78] Tom Lindberg (2016). White Paper: Building a larger and more robust marketplace for tracked and documented renewable power in Europe. ECOHZ. Retrieved from: https://www.ecohz.com/wp-content/uploads/2016/12/White-paper-building-a-larger-GO-marketplace.pdf

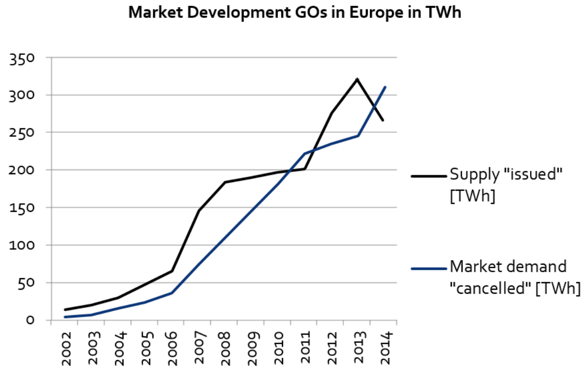
79ECOHZ (2015). Demand for renewable energy surges in 2014. https://www.ecohz.com/press-releases/demand-renewable-energy-surges-2014/

Figure 16-7 **Total Renewable Electricity Production in Europe**[80]



Prices for GOs are relatively low because supply exceeds demand. Figure 2-8 shows the development of supply and demand for GOs.

Figure 16-8 **Market Development of GOs in Europe**[81]



The prices paid by the end customer for GOs vary in the different EU countries. For example in Belgium, the electricity price with GO is 1-2 cents/kWh higher than without GO whereas the price in Germany is only 0, 5-0, 8 Cents/kWh higher than without GO.[82] Prices of GOs

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[80] Eurostat (2017). Energy from renewable sources. Eurostat statistics explained. Retrieved fromhttp://ec.europa.eu/eurostat/statistics-explained/index.php/Energy_from_renewable_sources

[81] ECOHZ (2015). Demand for renewable energy surges in 2014. https://www.ecohz.com/press-releases/demand-renewable-energy-surges-2014/

[82] ECOHZ (2015). Demand for renewable energy surges in 2014. https://www.ecohz.com/press-releases/demand-renewable-energy-surges-2014/

vary widely and depend on the technology, the region and the year in which the RE plant was built.

Case study: Mandatory GECs in Norway and Sweden

Sweden and Norway have had a joint market for green electricity certificates since January 2012. The common market was setup to increase market efficiency since it results in more market participants and more market volume than two separate national markets. The two countries have the objective to increase renewable energy production by a total of 28.4 TWh from 2012 to 2020. Sweden will contribute 15.2 TWh and Norway 13.2 TWh. Electricity produced from the following sources are eligible for GECs thus contributing to the goal: Biofuels (including CHP plants run by biofuels), geothermal energy, solar energy, hydropower, wind power, wave power.[83]Currently the Energy production in Norway is mainly based on hydro with a share of 94 % of total energy production. Energy production in Sweden is more diverse.

The common market of green electricity certificates is a mandatory market, which is independent from the GO market and exists in parallel. Both countries are also EECS certified and participate in GOs market.[84] In Norway, GEC are the only incentive scheme for RE.[85]In Sweden GEC are also the main incentive scheme for RE but there are also tax privileges regarding the Federal Real Estate Tax.

Market Mechanism and functionality

The size of the quota obligations is set by the Swedish and Norwegian Electricity Certification Act and creates demand for GECs. GECs are traded openly via the Nordic electricity stock exchange (Nord Pool exchange). The certificates are valid for one year. This means that certificate holders have to buy new certificates every year to meet their yearly quota obligation. If obliged parties fall short of buying the required number of certificates, a penalty equivalent to 150 % of the average certificate value for the given year, must be paid for each certificate missing. Eventually the end users pay for the development of renewable energy production because the cost of the electricity certificates is included in the electricity bills. Table 2-5 provides an overview of green electricity certificate market prices paid by market participants.

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[83] Energimyndigheten (2016). The Norwegian-Swedish Electricity Certificate Market. Annual Report 2015. Retrieved fromhttps://www.nve.no/Media/4750/elcertifikat-2015-en_web.pdf

[84] Energimyndigheten (2016). The Norwegian-Swedish Electricity Certificate Market. Annual Report 2015. Retrieved fromhttps://www.nve.no/Media/4750/elcertifikat-2015-en_web.pdf

[85] RES Legal (2017). Promotion in Norway. Retrieved fromhttp://www.res-legal.eu/search-by-country/norway/tools-list/c/norway/s/res-e/t/promotion/sum/378/lpid/379/

Table 16-5 Certificate price Norway and Sweden[86]

Year	Volume-weighted average annual price of certificates (Euro per certificate)	Electricity customers' average additional costs for green electricity certificates in Sweden (€/kWh)	Electricity customers' average costs for green electricity certificates in Norway (€/kWh)
2003	201	0,0016	
2004	231	0,0020	
2005	216	0,0024	
2006	167	0,0022	
2007	195	0,0031	
2008	247	0,0042	
2009	293	0,0055	
2010	295	0,0055	
2011	247	0,0046	
2012	201	0,0037	0,0006
2013	201	0,0028	0,0012
2014	197	0,0029	0,0022
2015	172	0,0026	0,0003
2016	158	0,0037	0,0032

Market Participants and Quota

The demand for certificates is triggered by quota obligations of certain market participants. The "quota curve" (see Figure 2-9) states the percentage of renewable electricity consumption, which customers with quota obligations must buy. In Norway the following market participants have quota obligations:

- Supplier of electrical energy to end users
- Consumer of electrical energy who consume energy that they have produced themselves

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[86] Energimyndigheten (2016). The Norwegian-Swedish Electricity Certificate Market.Annual Report 2015. Retrieved fromhttps://www.nve.no/Media/4750/elcertifikat-2015-en_web.pdf

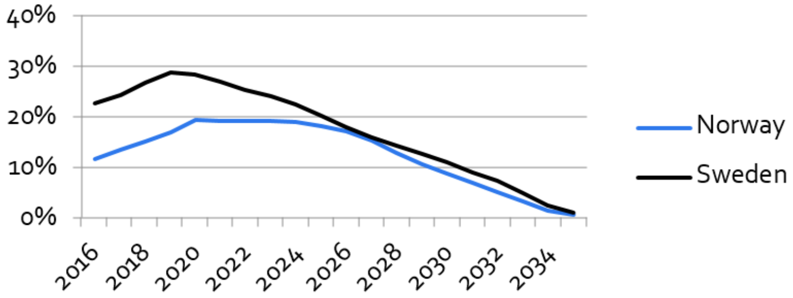
- Buyer of electrical energy for own demand on the Nordic Pool Spot market or through bilateral agreements

In Sweden the following market participants have quota obligations:

- Energy suppliers
- Consumer of electrical energy who consume energy that they have produced themselves, if the quantity of consumed electrical energy exceeds 60 MWh per year of calculation and has been produced in a plant bigger than 50 kW
- Energy-intense industry that have been registered by the Swedish Energy Agency

The quotas are specific to each country. Norway's quota runs from 2012 to 2035. The quota increases until 2020. Sweden's quota applies from 2003 to 2035.The quota peaks in 2020 and decreases afterwards.[87]

Figure 16-9 Quota obligation per MWh of electricity sold or consumed[88]



Goal Fulfillment

The electricity certificate system has contributed a total 13.9 TWh of RE production from new RE plants since the beginning of 2012. In 2015, Norway contributed approximately 2.1 TWh and Sweden 10.7 TWh. In order to achieve the target of 28.4 TWh by the end of 2020, the renewable energy production must increase by 3.33 TWh each year.

In 2015 a total of 19.7 million certificates were cancelled, which means deleted and thus energy from renewable electricity were used to fulfill the quota obligation (12.8 million of these were cancelled in Sweden and 6.9 million in Norway). Certificates that have been issued but not cancelled represent the electricity certificate surplus. A surplus arises

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[87] Energimyndigheten (2016). The Norwegian-Swedish Electricity Certificate Market. Annual Report 2015. Retrieved fromhttps://www.nve.no/Media/4750/elcertifikat-2015-en_web.pdf

[88] Energimyndigheten (2016). The Norwegian-Swedish Electricity Certificate Market. Annual Report 2015. Retrieved fromhttps://www.nve.no/Media/4750/elcertifikat-2015-en_web.pdf

because supply of GEC is higher than demand. Reasons for a higher demand are new plants that a phased in earlier and lower electricity consumption than planned thus less certificates cancelled. In 2015 the surplus of certificates amounts to 4.9 million in 2015.[89]

Case study: Voluntary GECs in Germany

Germany is participating in the GO market since 2013.[90]The market for GOs in Germany is voluntary and exists parallel to the FIT/FIP support scheme for RE. However, only renewable energy that has not been supported under the support scheme is eligible for GOs. In 2015, 25 TWh were eligible to GOs (14% of total renewable energy production in Germany). The issuing body for GOs in Germany is the Umweltbundesamt (UBA), Germany's central environment protection agency. The UBA is managing the registry for GOs.

As stated above electricity production from renewable energy in Germany is around one third. However, some end customers wish to receive electricity 100 % from renewable energy. The electricity from the grid is always a mix between different energy sources. To meet the demand for 100 % renewable energy, electricity supplier offer so called "Green Electricity Tariffs" to provide purchase alternatives beside the regular tariff. These GOs are managed in the registry at the UBA and every purchase transaction is tracked. As soon as the electricity within the green electricity tariff is sold to the end customer, GOs are cancelled and deleted from the registry accordingly. The costs for the GOs are passed to the end customer by the electricity supplier. Pricing is done individually by each electricity supplier and highly depends from the origin of the GO and if the GO comes with extra quality labels.

Figure 2-10 shows the relation between GO issuing, cancellation, imports and exports in Germany. The line graph shows that cancellation of certificates is relatively high whereas issuing is relatively low. As a result most of the GOs used in Germany are imports from other countries.[91]

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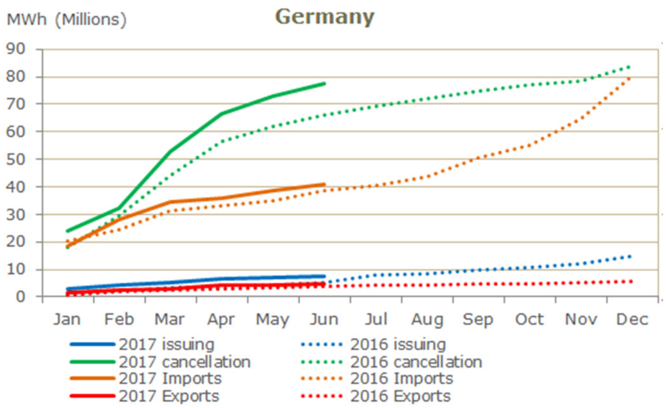
[89] Energimyndigheten (2016). The Norwegian-Swedish Electricity Certificate Market. Annual Report 2015. Retrieved from
https://www.nve.no/Media/4750/elcertifikat-2015-en_web.pdf

[90] AIB (2016). Germany, GOs, Renewables and UBA. Newsletter 26. Vol. 9 Issue 26. Association of Issuing Bodies. Retrieved from https://www.aib-net.org/documents/103816/-/-/c44d051d-6aa1-d821-5441-5599a4244815

[91] AIB (2017). National activity. Association of Issuing Bodies. Retrieved from
https://www.aib-net.org/documents/103816/175830/DE.png/9e5fce5c-08dd-93a3-1df1-

Figure16-10 GO market in Germany[92]



Case study:US market for GEC

In the US there are states with voluntary and states with mandatory markets for green electricity certificates. Green electricity certificates are called "Renewable Energy Certificate" (REC) in the US. RECs can be sold bundled or unbundled. Bundled RECs are tied to and only sold with the actual electricity from the renewable producer. Unbundled RECs are sold independently from electricity and only state the renewable attribute of electricity.

Voluntary markets

The voluntary green power market refers to the sale and procurement of renewable energy for voluntary purposes by residential and commercial customers. There are several mechanisms through which green power can be purchased. RECs are generally present in all of these types of products. The following table provides an overview. [93]

Table 16-6 Green Power Purchase Mechanism in US

Mechanism	Availability	Functionality	Pricing
Utility green pricing	40 states	In utility green pricing programs RECs are obtained by the utility and offered to customers bundled with electricity. Customers pay a premium to purchase RECs	Customers pay a premium above retail electricity rate, typically around $0.02/kWh

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[92] AIB (2017). National activity. Association of Issuing Bodies. Retrieved from https://www.aib-net.org/documents/103816/175830/DE.png/9e5fce5c-08dd-93a3-1df1-

[93] Eric O'Shaughnessy, Chang Liu, Jenny Heeter (2016). Status and Trends inVoluntary Green Power Markets. NREL. Retrieved from https://www.nrel.gov/docs/fy17osti/67147.pdf

		from qualified renewable energy projects	
Competitive suppliers	15 states	Customers in competitive electricity markets can buy electricity generated from renewable sources by switching to an alternative electricity supplier that offers green power.	Customers pay a premium above the competitive supplier's normal rate
Voluntary unbundled REC Purchase	All states	Regardless whether customers have access to a green power product from their retail power provider, they can purchase green power products through unbundled RECs	REC values depend on several factors, including the technology, the region, the volume purchased
Community choice aggregation (CCA)	7 states	Communities aggregate their loads to collectively procure green power as a bulk purchaser through an alternative electricity supplier.	Aggregators offer customer rates competitive with prevailing utility rates. Some communities choose to invest savings in renewable energy products at no net cost relative to utility service.
Community solar	25 states	Community or "shared" solar programs allow utility customers to purchase or subscribe to a portion of a larger solar project. Customers than receive the benefits of the energy that is produced by their shares. The structure of this mechanism differ, but a common model is for the RECs to be transferred to the utility to meet compliance with an RPS	Subscribers generally make an up-front payment for capacity ($1.60/W-5.60/W) in some projects subscribers may also pay on an ongoing basis

Voluntary Power Purchase Agreements (PPA)	All states	A number of corporations, universities and others have negotiated long-term purchases of renewable energy through PPAs	Customers negotiate a long-term fixed rate
Large commercial green power rates	Few utilities	Large utility customers purchase, through the utility, renewable energy from a specific facility in the utility service territory instead of negotiating a PPA directly with a generator	No information

In total, about 4.900.000 US electricity customers purchased approximately 74,000 TWhof green power in 2014 (see table 2-7). CCA was highest with regard to participants. This is mainly because with CCAs, whole communities join renewable energy programs. Voluntary PPAs were highest with regard to sales in MWh. different mechanisms to buy RECs in the US, the market is relatively broad and different products for different needs are available.[94]

Table 16-7 Market size of different mechanism in the US [95]

Mechanism	Participants	Sales (MWh)
Utility green pricing	743,000	7,040,000
Competitive suppliers	1,584,000	16,250,000
Voluntary unbundled REC Purchase	89,000	36,000,000
Community solar	42,000	150,000
CCAs	2,500,000	7,700,000
Voluntary PPAs	295	6,700,000
Total	**4,916,000**	**73,690,000**

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[94] Eric O'Shaughnessy, Chang Liu, Jenny Heeter (2016). Status and Trends in Voluntary Green Power Markets. NREL. Retrieved from https://www.nrel.gov/docs/fy17osti/67147.pdf

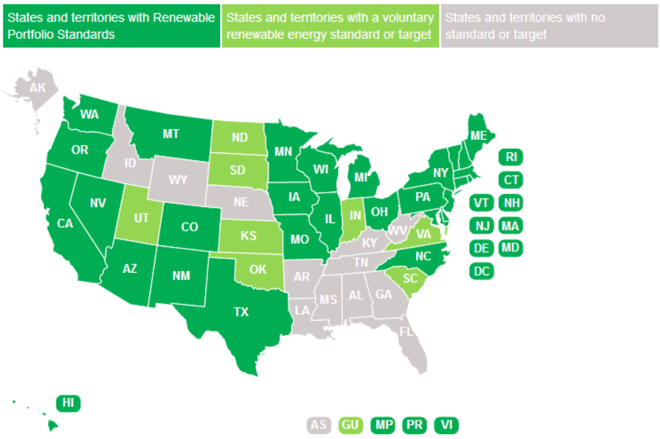
[95] Eric O'Shaughnessy, Chang Liu, Jenny Heeter (2016). Status and Trends in Voluntary Green Power Markets. NREL. Retrieved from https://www.nrel.gov/docs/fy17osti/67147.pdf

Mandatory markets

Mandatory Markets in the US are called compliance markets. Within compliance markets RECs are used to meet renewable energy quotas set by policies in Renewable Portfolio Standards (RPS). RPS are flexible, market based policies which ensure that public benefits of renewable energy are recognized. An RPS requires electricity providers to obtain a minimum percentage of their power from renewable energy resources by a certain date. To meet RPS requirements electricity sellers can either generate renewable electricity by themselves or by purchasing RECs from other generators. The requirement can apply only to investor-owned utilities or to municipalities and electric cooperatives.

In many states, standards are measured by percentages of kilowatt hours of retail electric sales. There is no national RPS. Renewable energy objectives and the development of RPS is in the responsibility of each state. Currently there are 37 states plus the District of Columbia that have RPS requirements or goals in place. Figure 2-11 gives an overview.[96]

Figure 16-11 Voluntary and mandatory RPS in the US[97]



Case study of USA case: mandatory GECs in California

California has one of the most ambitious renewable energy objectives in the country.[98]California has established a Renewables Portfolio Standard (RPS) Program, with the goal of increasing the percentage of renewable energy up to 50 % of electricity retail sales until 2050. The RPS requires that all sellers of electricity including publicly owned

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96 Jocelyn Durkay (2017). State Renewable Portfolio Standards and goals.National Conference of State Legislature (NCSL). Retrieved from:http://www.ncsl.org/research/energy/renewable-portfolio-standards.aspx#ca

97Jocelyn Durkay (2017). State Renewable Portfolio Standards and goals.National Conference of State Legislature (NCSL). Retrieved from: http://www.ncsl.org/research/energy/renewable-portfolio-standards.aspx#ca

98 IEA (2017). State –level Renewable Portfolio Standards (RPS). IRENA. Retrieved fromhttp://www.iea.org/policiesandmeasures/renewableenergy/

utilities, investor owned utilities, electricity service providers (ESP) and community choice aggregators have to procure a portion of their electricity retail sales from eligible renewable resources. This is done vie Renewable Energy Certificates (RECs). Currently 25 % of electricity is generated by RE in California.

In order to fulfill the renewable energy goals all sellers of electricity are required to buy RECs. The RPS allows partially the use of unbundled RECs from outside of California to be counted within the RPS. In the first trading period until 2013, unbundled RECs were allowed to contribute not more than 25 % of the total REC volume. In the second compliance period until 2016 unbundled RECs are limited to a maximum of 15 %, after 2016 to a maximum of 10 % of the total REC volume. This ensures that renewable energy used to fulfill REC quota is mainly from utilities within the state. [99]

California's three large investors owned utilities, which provide approximately 68 % of the states electric retail sales, collectively served 27.6 % of their 2015 retail electricity sales with renewable power. Under the existing law penalties are imposed on utilities that fail to meet their procurement requirements under the RPS. However, those potential penalties have never been clearly quantified. Nevertheless, a schedule for penalties for noncompliance is planned in the future.[100]

Case Study: Mandatory GEC market in Mexico

Green electricity certificates in Mexico are called Clean Energy Certificates (CEC) are used to ensure that clean energy goals are met and the certificates serve as the main subsidy scheme for clean energy. Suppliers of electricity are obliged to buy a certain number of certificates fixed by the Ministry of Energy (SENER). The first compliance period will be in 2018 with quota set at 5 % level. The reform is not implemented yet and still work in progress.

Clean Energy Certificates are awarded to clean energy generators (1 CEC/MWh), all clean energy facilities developed after 2014 will receive the certificates over a period of 20 years. CEC's are bankable and there is a penalty for non-compliance. The CEC's can be purchased and sold under monitoring of the Regulator (CRE).

The government sets the renewable energy objective and the amount of certificates, and the market determines the prices of the certificates that will ensure that goals are achieved, and thereby indirectly also the level of subsidies provided to clean energy. The additional costs for the certificates are paid by the electricity consumers as a surcharge on top of their electricity bill.

SENER evaluates the expected development in the electricity consumption, the volume of existing clean energy capacity and forecasts the number of additional certificates required per year. The estimated total generation and consumption in future years is an important

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[99] DSIRE (2017). Renewable Portfolio Standard. NC Clean Energy. Retrieved fromhttp://programs.dsireusa.org/system/program/detail/840

[100] California Public Utilities Commision. (2017). California Renewables Portfolio Standard (RPS). Retrieved from http://www.cpuc.ca.gov/renewables/

factor in determining the required number of clean energy certificates. The quota will start with 5 % certificates required from new projects in 2018 and will increase to 13.9 % in 2022.

CEC are traded within auctions parallel to energy and capacity. Auctions are technology neutral, i.e., all clean energy technologies can participate in the auctions. Auctions are the centerpiece of the Mexican energy reform.

The state owned power Generation Company CFE has been the single buyer of CEC within the auctions in 2016. In 2018, auctions will be opened to other market players, for example qualified buyers (e.g. industry with demand above 1MW). From 2018 there will be a spot market for CEL and the incentive scheme will be fully integrated.

CFE must determine the maximum price, namely setting maximum prices for capacity, energy and CEC, taking into account the price expectation of renewable energy development and subsidies in other countries in order to determine prices which are high enough to create incentives. The regulator CRE sets guidelines for the CEC supply (see table 2-8).

Table 16-8 Percent of renewable in total quantity & maximum price determined by CFE in Mexico

% of total quantity	
At least 80%	Shall be priced below 95% of the maximum price
At least 60%	Shall be priced below 90% of the maximum price
At least 40%	Shall be priced below 85% of the maximum price
At least 20%	Shall be priced below 80% of the maximum price

The CEC-market in Mexico is basically organized in a market-based environment. However, there are strict guidelines on the market design and market participants. Pricing is fixed on the demand side by CFE, which is currently also the only buyer in the CEC-market. Competition mostly applies on the supply side amongst the power generation companies. In 2018 auctions will be opened up, so more qualified buyers are able to participate in the market. Not all details of the system are finished yet, so continued monitoring of the implementation will be necessary. [101]

Conclusion

Trend of renewable energy incentives

Even though there certainly is not one ideal scheme that fits all countries' requirements and each country has to consider its specific circumstances, there are some lessons to learn from the above mentioned case studies for China. The case studies show that many

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[101] DEA (2017), Clean Energy certificates in Mexico.

countries have successfully refined their RE support mechanism from an FIT or quota scheme to a more market oriented FIP scheme.

Not just in China it becomes clear that FIT schemes are suitable to start-off RE development dynamically but their efficiency suffers when it comes to reflecting the actual cost developments in the industry properly.

The German case of changing the support scheme for offshore wind from FIT to FIP stands as an example for one possible way how, coming from a powerful FIT scheme, introducing a more market based approach can reduce the costs significantly. The existence of functioning market structures and supply chains was a precondition for the successful establishment of an auction based FIP scheme and the resulting cost reductions.

Likewise, the United Kingdom (UK) is an example for a country that moved from a quota based system to an FIP scheme with flexible premiums and more market integration. At the same time, the case study shows that a market-based RE support scheme has the potential to significantly reduce costs for the energy consumer compared to schemes that rely on more inflexible, regulated planning structures. For China, this means that while the introduction of a mandatory quota system may have positive effects on China's energy targets, further steps towards market development, e.g. a comprehensive power sector reform, are recommended. The implementation of an additional incentive scheme via certificates and mandatory quotas needs to get properly aligned with the market development process in order to avoid contradictory political signals and ineffective pricing and incentive mechanisms.

The case studies also show that introducing a more market based RE support scheme does not mean to give up the state's steering capabilities. As the Mexican case illustrates, the support scheme can be designed in such a way that the development of specific technologies is incentivized and regional grid specifics are taken into account. The requirements of reconciling the perspective of "best available natural resource" and "cost-efficient integration into the existing grid and demand structure" are easier to be best met in the context of an open and competitive auctioning process.

Market designs for the use of GECs

- **Clear goals are key.** The EU and China show common characteristics regarding the t availability of renewable energy resources in different regions. Within the European market, GOs do not serve as an incentive for further investment in RE. This is mainly because prices level are depressed due to a high supply of GOs from Scandinavian hydro power plants and the existence of individual national support policies. Energy volumes from RE that are supported by FIT/FIP distort the initial approach of the market scheme because they do not qualify for GOs and are excluded from the market. That leads to a. relevant energy volumes from RE that cannot be certified and traded within the GO market scheme and b. a lack of connection between the national RE production and the certification of electricity.
- **Challenges in voluntary markets.** Credibility of the GO scheme has suffered a lot

among consumers with high sensitivity to the "green" characteristic of their energy. In Germany, there was a lot of criticism about so-called "green-washing" of electricity and various groups demanded a proper regulatory framework to enable the connection of the local RE production with the local consumers. With regard to China, it can be concluded that a nation-wide support system with a harmonized mix of instruments is important to achieve an effective market pull for GECs.

The absolute level of prices of GECs in comparison to other support policies like FIT are the key factor if an investment incentive is being created by the use of GECs.

- **How mandatory GEC markets can work**. In mandatory markets, GECs often are the main incentive scheme for the development of renewable energy. The common market in Sweden and Norway is a good practice example for the use of GECs. Specific goals were set and further investments in RE are being incentivized, especially in Sweden. The development in both countries is according to plan and quota obligations are fulfilled. However, the Swedish/Norwegian case also illustrates potential challenges with regard to particular interests, when the incentive scheme is very strictly oriented towards cost efficiency. A proper balance of the interests of both countries to develop their non-hydro RE base is prevented by the higher cost structures in Norway. Mexico will establish a mandatory market for CEC with quota obligations for various market participants next year. Despite its relative complexity, the overall design of the new regulation is taking into account many aspects that are of relevance to the overall energy system. Since the details of the CEC regulation are still work-in-progress, the functionality of the specific design and execution of the CEC system cannot be evaluated yet. There may be useful Lessons Learned that can be regarded when a mandatory certificate market in China is getting designed in more detail. Voluntary markets have the objective to offer purchase alternatives for electricity customers. In this regard, the voluntary market(s) in the US offer various purchasing alternatives for customers who wish to buy renewable energy products. There are various options for customers and it is possible to choose what kind of renewable energy project to support. Voluntary markets are more effective if the electricity customer can chose between a range of product alternatives. The market in the US provides interesting examples of different market set-ups.

It can be summarized that there are many examples of existing GECs systems. In mandatory markets as well as in voluntary markets the system design determines if it's successful. In order to develop effective incentive schemes the examples provides the following lessons learned.

- Prices for certificates need to be high enough to create incentives
- The underlying structure of the market mechanism must take the needs of all participating regions into account
- The design of voluntary markets must take the customer needs into account, it is more effective if customers can support local projects with GECs

- It is essential to define clear objectives that should be achieved with the certification system before the implementation. The market mechanism needs to be tailored to the requirements of the objective.

16.3 Analysis on China nnovative incentive mechanisms of renewable power

With the expansion of renewable energy development scale, and the continuous rising of renewable energy's proportion in power and energy system, the guaranteed FIT for renewable energy power used at the growth stage in the past is no longer suitable. In other words, the mechanism needs innovating. When the economic competitiveness of renewable energy gets stronger and stronger, it is time for it to gradually enter the market. However, a preliminary power market must be established first, and more importantly, a platform for fair competition must be available. No matter what means is adopted, regulation by policy is required so as to reflect the real cost of each link in the power system chain, including the cost brought by the external and flexible power output of fossil energy. During the period of "13th Five-Year Plan", it is necessary to explore, pilot and innovate on new mechanism for renewable power price subsidy based on the reform process of power system, especially the reform process of power transmission and distribution prices and power prices formed by market trading of power.

This section puts forward innovation mechanisms, such as the FIP mechanism, bidding mechanism and green certificate trading mechanism of renewable energy, qualitatively analyzes the characteristics, feasibility and possible implementation paths of each mechanism, quantitatively analyzes the impact of green certificate trading mechanism on renewable energy enterprises and coal power enterprises. Besides, it compares and analyzes the implementation and cohesion among such innovation mechanisms.

Study on feed-in-tariff to feed-in-premium mechanism

Concept and connotation

Current pricing mechanism of renewable energy is differential subsidy. Based on the power transmission and distribution reform and the process of power marketized trading, this needs to gradually change to FIP mechanism based on the amount of power, disconnecting from coal power price. Besides, renewable power needs to participate in the power market step by step, and differential subsidy or FIP standard shall be adjusted duly and reasonably. In fact, FIP mechanism is a foreign premium subsidy mechanism, i.e. the generation benefits of renewable energy power generation enterprises come from power selling income obtained through price competition in power market as well as national policy subsidy capitals under the condition of no other economic policies (e.g. quota and green certificate). Under the FIP mechanism recommended in this section, generation benefits can be classified into two parts: the first is a price formed through various power price competitions (in demo area of power reform) or the original coal environmental benchmark power price paid by grid enterprises (in the area where existing power price is maintained), and the second is from the FIP from Renewable Energy Fund.

Purposes and principles

There are two key principles for FIP for renewable power in China: the first is with market being dominant, renewable power should be, which is now developing maturely and steadily, integrate with power market step by step. The whole design shall be compatible with the power market; the second is to reflect technological change and market maturity. The cost of renewable energy plus fair return is still the basis for determining the demand and level of renewable energy subsidy. In addition, reasonable price framework with other power sources in the power market also need to be considered to establish a price subsidy mechanism which complies with market competition principles.

Framework and method

Suggestions on the framework of implementation path for FIT tranfering to FIP mechanism are as follows:

- **Implement by technologies.** Implement mechanism reform for the renewable power with relatively mature technology and market first. Based on the development of various kinds of renewable power, it is suggested to implement FIP for onshore wind power and large PV first. Biomass generation technologies are also relatively mature, but the market is limited and the potential of reduction of cost is also limited. Therefore, the subsidy policy for biomass generation can be introduced together with the FIP policies for onshore wind power and large PV, or introduced when the FIP mechanism is stable and mature. Offshore wind power and CSPare still at the development stage in technology, so it is suggested to give priority to fixed or benchmark power price policies with bidding power price as a supplement, so as to support their growth and development with relatively stable policies and profit level.

- **Take into account the smooth cohesion among existing project policies.** For existing projects, it is required to consider their possible benefits in the power market, so as to make sure the profit level of the whole sector is basically equal to that of the original mechanism after mechanism reform. If green certificate trading mechanism of renewable energy is implemented, it is also required to consider the benefits of green certificate and make corresponding adjustment for the FIP subsidy level of new and existing projects. But for existing projects, the profit level of the whole industry must be equivalent to that of the original mechanism after mechanism reform or with new projects added.

- **Implement in Pilot regions first.** It is suggested to primarily determine FIP standard and implement FIP policy in pilot provinces (municipalities, regions) first, where are the pilot areas forpower transmission and distribution reform and power market trading. Such provinces (municipalities, regions) are in economically developed eastern and central areas in general, which are the priority areas for the development of renewable energy in near term.Under current benchmark power price of renewable energy and differential subsidy mechanism, their differential subsidy standard for the same renewable energy technology is usually at a relatively low level in China. Thus, these areas are priority choices for renewable energy development. Exploring suitable marketization modes in such areas to promote industrial upgrade and cost reduction of renewable energy technologies would set a better example.

- Adjust the level of FIP. FIP level must be adjusted in time, and a short-cycle assessment and adjustment mechanism (if it is based on the coal electricity linkage mechanism, then it shall be assessed by a third party every half year. After that, the decision-making department will determine whether to adjust or not and how much should adjust) needs to be established when other conditions are changed (such as when the average FIT formed on the basis of coal power benchmark price or market price competition is changed, and green certificate trading mechanism of renewable energy is implemented).

Implementation path

Suggestions on the ways of determining the subsidy level to new projects

The ways of determining the subsidy standard and level of new projects are suggested as follows:

- Determine a proper FIP standard. First, the cost, the development orientation and the demands for a development layout in terms of time and location, of different renewable energy technologies at different development stages should be considered. Second, the resource conditions, power market characteristics and market price levels of renewable energy in various provinces (municipalities, regions) also shall be considered.
- Adjust FIP standard regularly. If the adjusting level is applicable to all the new projects after the reform of FIP mechanism, then the FIP must also be applicable to all the new projects after each adjustment. When making a decision for a project, for one thing, renewable power enterprises need to take into account changes in the price formed by power market; for another, they should estimate the impact on project’s economy from adjusting and changing the FIP standard.

Suggestions on the ways of determining the subsidy level of existing projects

The ways of determining the subsidy standard of new projects are much more complicated, especially for onshore wind power and PV projects. There are numerous existing projects which are distributed widely. The benchmark power price differs greatly since it had been adjusted for many times. Coal power benchmark price standard is different in every province. All of the aforementioned factors pose challenges for adjusting the subsidy mechanism of existing renewable energy projects and determining its level. Suggestions and analyses on feasible programs are as follows.

- Link up two mechanisms for existing projects seamlessly

  Namely, if the coal power benchmark price in one region determined during the operation period of renewable energy power generation project is A, the benchmark price of environmental-friendly coal power is B, then the FIP standard for renewable energy power generation project during this period is A minus B. FIP standard determined in this way is called the FIP with tax.

When great changes take place in trading power price of power market (in power marketization regions) or coal power benchmark price, the FIP level needs to be adjusted. It is suggested to make uniform assessment nationwide or make corresponding assessment as per large regions, and determine a uniform range of change in FIP.

In particular, in major hydro power provinces, such as Sichuan, Yunnan, Hunan, Hubei and Qinghai, since the local coal power benchmark prices (including desulfuration, denitration and dust removal) are significantly higher than the actual average purchasing price of grid power, under benchmark power price and differential subsidy mechanism, the gap between coal power benchmark price and the actual average purchasing price of grid power is footed by grid enterprises in practice and relieved through power selling price. But after the FIP mechanism is implemented, the power price is formed through market and the grid will no longer bear this expense. For this reason, such practical needs of non-water renewable energy power generation projects in major hydropower provinces (municipalities, regions) needs to be taken into consideration when considering FIP standard. This problem exists for both existing projects and new projects, so it must be considered.

- Determine a relatively uniform per-kWh subsidy standard based on the resource zoning of renewable energy

  The resource zoning of renewable energy, such as wind power and PV shall be re-determined through corresponding reasonable adjustment based on existing resource zoning of renewable energy. Based on the renewable energy resource conditions and current resource zoning of different provinces (municipality, region), the supply, demand and price of the power market in each region need to be considered. According to the principle that the average rate of return basically keeps the same after the reform of two mechanisms, with smaller difference within the same region, a relatively uniform per-kWh subsidy within each region could be determined.

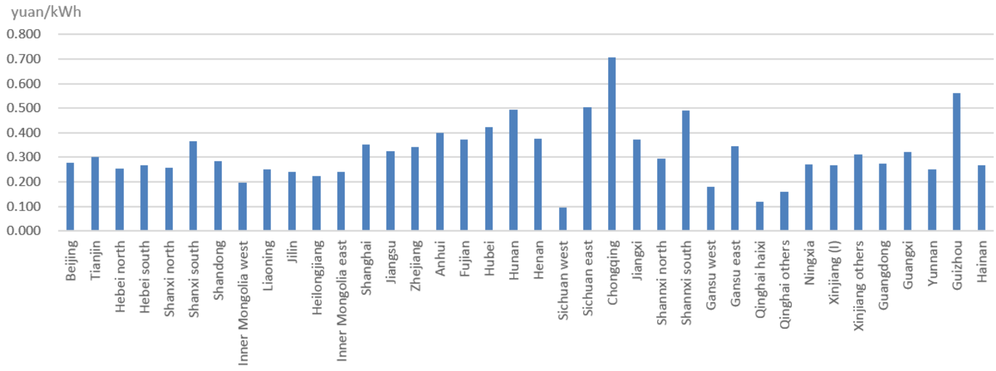
  In case of great changes in trading power price of power market (in power marketization regions) or in coal power benchmark price, the FIP level needs to be adjusted. It is suggested to make uniform assessment nationwide or make corresponding assessment as per resource zoning and determine a uniform range of change in FIP

Design of FIP level

The new grid-connected PV projects in 2018 are taken as an example to calculate the FIP level. The resources in different regions are calculated according to monthly statistics recorded by 96 meteorological stations across the nation in 10 years. Considering 80% of large PV projects' efficiency, the initial investment is predicted to be 6000RMB/kW.

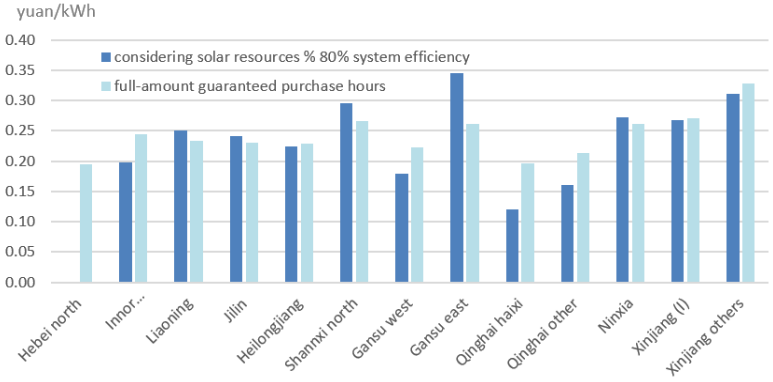
It can be learnt from Figure2-12 that FIP demand in western Sichuan is less than RMB 0.1/kWh; that of Qinghai and Western Gansu is between RMB 0.12/kWh and RMB 0.18/kWh; some regions are in relatively poor condition in terms of solar energy resource, with FIP subsidy demand of higher than RMB 0.4/kWh, including Chongqing, Guizhou, other regions of Sichuan, Southern Shaanxi and Hunan; the FIP demand of most regions in China is between RMB 0.2/kWh and RMB 0.4/kWh, but there are still certain differences among the FIP demands of these provinces (municipalities, regions). If it is calculated as per annual utilization hours for full-amount guaranteed purchase, FIP demand of Qinghai and northern Hebei is about RMB 0.2/kWh, while that of other provinces and regions increases, but still within RMB 0.2-0.4/kWh. (See Figure2-13).

Figure16-12 Calculation results of FIP demands for large PV plants by region in 2018



(assuming 80% system efficiency)

Figure 16-13 Calculation results of FIP demands for large PV plants of select regions in 2018



Study on bidding mechanism for renewable power pricing

Roles and possible effects

At present, many countries apply bidding mechanism for pricing renewable energy. Bidding mechanism mainly can be adopted at two stages during renewable energy development. The first stage is the start-up and demonstration stage of market. China applied project bidding to onshore wind power in 2003-2009, offshore wind power in 2009, and PV around 2010, for at that time, there were less projects, and there was no real cost data or approximate cost data to support adopting FIT or pricing-by-project mechanism. But the bidding power price mechanism offered one way to find out cost and power price demands. China launched the first batch of CSP pilot projects from 2015 to 2016, and the power price of that has similar nature. The second stage is the mature stage of large-scale development of renewable energy market. For example, the power price bidding of advanced technology PV base in 2016 was based on a great deal of practical experience and historical data. Through biding, the major goal is to maintain the development scale of renewable energy, optimizing the layout and realizing an orderly development. At the same time, the cost and price demands, reducing power price and improving the utilization efficiency of subsidy capital can be gotten.

Based on the bidding situation of PV at the trial large-scale development stage, bidding pricing has achieved results at multiple levels, with valuable experience and lessons. Analyses on the effects and experience of the power price bidding of trial PV in China in 2016 are as follows.

- the biding price mechanism coordinates with the orientation of power market marketization
- the price of grid-connected electricity can be found through competition, so that the subsidy per kWh can be reduced reasonably
- pricing though biding can establish a relatively fair competitive environment, which can help edged enterprises to develop.
- Establishing a normative order in project development can help optimizing the whole structure and layout.

In effect, the bidding of Advanced Technology PV Base has remarkable effect on decreasing power price. In particular, bidding form may solve the problems of trading government's approval on projects, reducing non-standard and unreasonable extra charges applied to PV projects by local departments. In the long run, bidding competition is not only consistent with international development trend but also beneficial to the sustainable and healthy development of PV industry in China. The objectives of cost and price demands of PV have been realized preliminarily through bidding. However, it is still necessary to make deeper analysis, build a price linkage model and gradually establish a benign linkage mechanism between PV bidding price and benchmark power price or FIP, so as to determine how bidding price will affect fixed or power price subsidy.

Implementation path

In terms of bidding form of power price, the bidding pricing is compatible with various power price mechanisms, so both fixed bid power price and bidding with fixed subsidies are acceptable. Therefore, bidding pricing may be implemented in parallel with existing FIT policies, FIi policies which will be gradually changed in the future, and various economic incentive policies where green certificate trading is considered.

Bidding pricing of renewable energy is a competition mainly lies among renewable energy projects with similar technology or various technologies; other non-renewable resource projects are excluded. Therefore, it is feasible to design the bidding pricing mechanism only from those perspectives like how to promote renewable energy development, optimize the layout and develop at an appropriate pace.

The bidding 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, the 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" period.

Study on green certificate trading mechanism for renewable power

Concept and connotation

Green certificate of renewable power system is a system set up to develop renewable power through market mechanism on the basis of mandatory quota of renewable power generation. Mandatory market quota and green certificate trading mechanism is an internationally mature system for promoting renewable power development. As for its connotation, a green certificate is issued when the power generated by renewable energy reaches a certain scale (generally 1MWh). Meanwhile, for power enterprises or power grid enterprises, a proportion of renewable power generation in the total power generation and a proportion of renewable energy electricity sales in the total electricity sales is required. The enterprises failing to reach the above proportions need to purchase a green certificate in the market. Renewable power generation enterprises may obtain corresponding proceedings by trading green certificates.

Proposed framework

From the domestic demand point of view, it is necessary to launch a trading mechanism as soon as possible for mandatory quota and green certificate restraints, the quota-responsible subjects may be selected from power generation enterprises and electricity sales (grid) enterprises.

If the coal-fired power generation enterprises serve as the quota-responsible subjects, fulfilling quota responsibility and purchasing green certificate would be a great way for them to shoulder social responsibilities. It is also an approach for fulfilling social responsibilities and paying external expenses. Speaking of the promoting effects on renewable energy development, if the coal-fired power generation enterprises serve as the quota-responsible subjects, not only can the renewable energy power projects increase their green certificates earnings, but also coal power enterprises may increase the costs that reflect part of their externalities, thus narrowing the gap between renewable energy cost and fossil energy cost. This can help realize the objectives of subsidy reduction and fair price regarding renewable energy power generation in advance, reducing the demand for subsidy capitals.

If the electricity sales (grid) enterprises serve as the quota-responsible subjects, there are several advantages, including reduce the demand for subsidy capitals, resolve and at least contribute to alleviating the problem of renewable energy power rationing, and by setting proper quota targets, provide a stable and sustainable growth space for renewable energy development in the future, ensuring the realization of the 2020 and 2030 national proportion target for non-fossil energy. From international experience and long-term development of renewable energy, the advantages will be more significant if the electricity sales (grid) enterprises serve as the quota-responsible subjects.

Green certificate price calculation

The estimation of green certificate price is done on the condition that power generation enterprises serve as the subject responsible for quota and green certificate trading.

Option 1: estimating the green certificate price on the condition that wind power can sell at the same price as coal power depending on certificate earnings by 2020. The average price of each green certificate (1MWh of non-hydro renewable energy power) is estimated to be about RMB 78; for power generation enterprises, the additional cost for purchasing the certificates is RMB 12 as converted when 1 MWh coal power is generated.

Option 2: estimating the green certificate price when the surcharge level of renewable energy remains unchanged, and all funds are used as subsidies to renewable energy power price. The average price of each green certificate (1MWh of non-hydro renewable energy power) is estimated to be about RMB 102; for power generation enterprises, the additional cost for purchasing the certificates is RMB 15.7 as converted when 1 MWh coal power is generated.

Economic impacts attributable to its implementation

If the coal-fired power generation enterprises serve as the quota-responsible subjects, implementation of green certificate trading will cause certain economic impacts on fossil energy based power generation enterprises, and these impacts are related to green certificate price and the proportion of non-hydro renewable energy among enterprises.

Taking a power generation enterprise with one 300MW coal power unit as an example, if the annual average utilization hours reach 4,500, the annual power generating capacity will reach 1.35TWh. If the enterprise only has the coal power projects but do not have any other renewable energy power generation projects, calculated by Option 1, the price of each green certificate will be RMB 78, and the cost for coal power will be increased by RMB 12/MWh. Therefore, about 226,000 certificates will be purchased every year on average, and about RMB 16.2 million will be paid to purchase green certificates every year. Calculated by Option 2, the price of each certificate will be RMB 84, and the cost for coal power will be increased by RMB 12.9/MWh. Therefore, about 226,000 certificates will be purchased every year on average, and about RMB 19 million will be paid to purchase green certificates every year.

If this coal power enterprise with a capacity of 300MW chooses to reach the quota proportion not by purchasing the green certificates but by investing the construction of wind farms, and assuming the annual equivalent utilization hours for wind power is 2,000h, then it will need to construct a 104MW wind farm. If the unit investment in wind farms is RMB 7,500/kW, RMB 780 million is needed for investment in-construction.

If the electricity sales (grid) enterprises serve as the quota-responsible subjects, additional power price will be directly reflected in the terminal power price according to the power system reform scheme and its supporting documents. If above parameters for the calculation of green certificate price are applied, by 2020, the terminal power price will be increased by RMB 7/MWh according to Option 1 and by RMB 9/MWh according to Option 2.

Connections with other mechanisms

Connections with Renewable Energy Power Price Subsidy mechanism and full-amount guaranteed purchase mechanism

In an ideal power-market-mode stage, green certificate prices may become an alternative source of fixed subsidies, hence directly reducing the needs for financial subsidies. Because renewable energy gains a preferential access to grid connection with its low operating costs, it no longer has special needs for full-amount guaranteed purchase. The effects of full-amount purchase may be fully realized during its implementation.

In a transition stage prior to the arrival of the ideal mode, there exists a high proportion of planned electricity in the market. Even if a fairly large portion of the planned electricity is left for renewable energy, under the present circumstances of low electricity demands, curtailment may still be inevitable. Planned electricity may be interpreted as the amount of electricity eligible for national tariff subsidy under the full-amount guaranteed purchase mechanism; the remainder of the electricity produced may either be still eligible for tariff subsidies, or be rejected. But above all, this part of electricity needs to be sold and yield income through multilateral or bilateral transactions. The electricity in both cases, though, is eligible for green certificate, and hence able to yield income through green certificate trading. As a result, renewable power generation projects during this stage may yield income from three sources: the first is "guaranteed electricity quantity"* (market price + tariff subsidy); the second is "additional electricity quantity"* (agreed price + tariff subsidy (or 0)); and the third is "certificate corresponding to total electricity quantity"* certificate price.

<u>Connections with carbon emissions trading system</u>

The essence of carbon emissions trading system (ETS), being one of the effective tools for achieving greenhouse gas (GHG) emissions reduction through market means, is to give enterprises the right to emit by way of quota allocation under the premise of government control over total emissions. Enterprises with high emissions reduction costs may seek to meet the goal of achieving emissions reduction at minimum costs by purchasing the right from other enterprises with excess quotas or by Verified Emission Reductions (VERs). The Chinese government initiated a national carbon emissions trading system in 2017.

Generally speaking, there are both similarities and correlations between China's carbon emissions trading and the planned renewable energy green certificate trading, mainly embodied in the following aspects: firstly, the national total emissions targets and the performance targets for responsibility subjects are all mandated by the State; secondly, the two are similar in ways their quota fulfillment requirements are set. Under both mechanisms, enterprises are free to choose a way to fulfill their quota requirements, either through quota or certificate trading or by reducing emissions, producing or purchasing green electricity. The prices of carbon emissions quota and renewable energy green certificate will become a key factor affecting enterprise behaviors; thirdly, all power companies are responsibility fulfillment subjects and trading subjects; and fourthly, renewable energy projects can produce Chinese Certified Emission Reduction (CCER). Currently, it is common that carbon emissions trading pilot projects may require usage rate of CCER be no more than 5% of the year's quota quantity.

There are also differences between China's carbon emissions trading and the planned renewable energy green certificate trading. Main differences are as follows: firstly, difference in verification difficulty. Carbon emissions trading market requires more stringent verification procedures and methodologies, whereby green certificate trading is much easier to get started; secondly, difference in coverage scope. In a carbon emissions trading market, power companies may fulfill their responsibilities by purchasing carbon quotas from other industries; whereby in a renewable energy green certificate trading market, power generation or sales enterprises have no better way but to purchase certificates from green power generation enterprises to comply with the requirements; thirdly, difference in market price formation mechanism. In the case of a carbon emissions trading market, primary market prices may be formed through auctions, and secondary market prices can be formed jointly by supplies and demands of the secondary market together with the primary market prices. A renewable energy green certificate trading market, however, has no auction at all, so the transaction prices are totally based on supplies and demands; fourthly, fundamental difference in existing and incremental quantities. A carbon emissions trading market is essentially one in a "from top to bottom" quantity-reduction allocation mode on the basis of determined total carbon emissions, whereby a renewable energy green certificate trading mechanism is one that is bound by proportion indicators, against which enterprises bearing fulfillment responsibilities need to increase their green certificate holdings for the purpose of complying with the requirements. The total amount of certificates, therefore, is likely to rise on a continuous basis.

In the context of current policies, carbon emissions trading and renewable energy green certificate trading mechanisms are designed and implemented in a comparatively independent way. In the long term, under the preconditions of: a more sophisticated national carbon emissions trading market; rationally developed total emissions targets and allocation plans; gradually unified local rules; more transparent carbon emissions data of main participants; more standardized verification and quota settlement procedures at provincial and local levels; sufficiently active market transactions; and particularly, that renewable energy green certificate is deemed to have equal effects as carbon emissions and hence a valid basis for offsetting enterprises' carbon emissions quota, then the green certificate system will gradually converge with the carbon emissions trading market.

But in the short term, due to the uncertainties surrounding the carbon emissions trading market, which prevents it from running in an anticipated way, most carbon emissions quota are issued for free. Any CCER Projects eligible for offset credits must go through a complicated process filled with "externality" testing or argument with designated methodologies. As a result, the total amount of qualified projects is far from sufficient to meet the needs of large-scale renewable power generation across the country. Hence, the aim to "cut down" national renewable power tariff subsidies by setting up a "carbon emissions trading" market can hardly be achieved in the short term. Nevertheless, active efforts are still needed to enable renewable energy green certificates to participate in the carbon emissions trading market, and to expand the CCER offset ratio of renewable energy projects. It is also necessary to urge the administrative departments of climate to intensify the mechanism for total carbon emissions control and paid auctions, improve the economic competitiveness of renewable energy, and create a good environment to support sustainable development of renewable energy.

16.4 Implementation path of renewable energy incentive mechanism framework

It is necessary to properly adjust the policies and mechanism for renewable energy according to the development situations and demands, including mechanism innovation, adjustment of existing mechanisms and policies and abolishment of improper mechanisms. This section focuses on the development path from now to 2030. According to the State Policy Scenario, and the demands for renewable energy development in 2°C scenario and the transition process of energy power system proposed in Part B, the following implementation paths of incentive mechanism framework are proposed respectively.

Policy framework under state policy scenario

Policyon renewable energy pricing

The framework and path regarding renewable energy power price policy is shown below: the power price marketization reform of the power system reform will be completed by 2025, and renewable energy will have a full access to the market. By 2020, FIP policy for the transformation of FIT will be implemented for mature renewable energy technology with a large market scale. During 2020-2025, renewable energy power will be fully involved in market competition except for individual demonstration technologies.

- Onshore wind power and PV: FIT policy will be implemented for onshore wind power and PV, and FIP mechanism for transformation will be fully implemented around the Year 2020; FIT or subsidy will be reduced, and the subsidy to new onshore wind power and PV will be reduced to 0 during 2020-2025; subsidy to distributed PV of buildings will be reduced to 0 around the Year 2025; and subsidy to other distributed PV will be reduced to 0 during 2020-2022.
- Offshore wind power and CSP: relatively high FIT policy will be implemented before 2025 or whenever the installed capacity reaches 10GW, and it will transform to the FIP mechanism afterwards. The subsidy will be reduced to 0 during 2025-2030 (the specific cancellation time depends on technology development and conditions of green certificate market, carbon market, etc. However, if the cost at that time is not significantly reduced compared to2015, the support will not be offered in this aspect anymore).
- Biomass power generation: the power price policy will be transformed into FIP around the Year 2020, and the power price subsidy will somewhat decrease according to the conditions of green certificate market, carbon market, etc. By 2030, the subsidy will have been reduced to 0, and benefits from garbage power generation will include bidding of power market + green certificate and carbon market + higher garbage disposal fee; benefits from biogas power generation or CHP will include bidding of power market + green certificate and carbon market + heating fee + reasonable waste disposal fee; forest and agricultural residues will be used for CHP or mixed fuel.
- Other renewable energy power generation: the scale is limited, and the heat is provided by demonstration or FIT; promote the heat price marketization process, and let the renewable energy heating price be decided by the market.

For policy on other renewable energy product price, the implementation path of the framework is shown below:

- Gas supply: terminal subsidies are provided for biomass gas supply. During 2020-2035, subsidies will be gradually cancelled according to mandatory market establishing process.
- Fuel: existing price policies are still applicable to liquid fuel. For second-generation or higher generation fuel ethanol, the terminal products are priced in those periods

without economic competition and distributed in certain sales regions.

Mandatory market policy

Mandatory market includes quota and green certificate trading system, and the market includes voluntary market and mandatory market. Implementation path of the framework:

- In 2017, establish a market where renewable energy power green certificate may be voluntarily traded
- In 2018, start the mandatory trading market for renewable energy power quota and green certificate; in 2020, fully complete the construction of mandatory trading market, develop proportion requirements that increase year by year, The green certificate price in the mandatory market will be determined by transaction, and an appropriate certificate buyout standards will be determined as well(for example, the price is RMB 100/MWh during 2020-2030, to be continuously implemented after 2030)
- Gradually establish the system for mandatory installation or heating proportion for renewable energy heating in new buildings and industry.

Policieson tax and fee

Implement long-term VAT exemption policies for various types of CSP, and develop tax exemption policies for heating by renewable energy and gas production through biomass purification.

Financing policy

For renewable energy policy projects determined by the State, such as PV poverty alleviation project, continuously arrange preferential credits for support.

Policy framework under 2° C scenario

On the basis of incentive policies under State Policy Scenario, the following policies are suggested to implement.

Policyon renewable energy pricing

In terms of policy on renewable energy power price, the implementation path of framework is shown below:

- During 2018-2020, significantly raise the surcharge standards for renewable energy power price, for example raise it to RMB 0.03/kWh, and satisfy the demands for renewable energy subsidy in the near term when the mandatory quota and green certificate system are not fully established and carbon price is still low.
- Reform of terminal power price: gradually reduce the scope, amount and level of crossing subsidies, and cancel crossing subsidies among various types of users by 2030.
- The power price marketization reform of the power system reform will be completed by 2023, and renewable energy will have a full access to the market.

- Generally raise the municipal waste disposal fee; strengthen supervision and punishment on organic waste disposal so as to raise the market price for organic waste disposal by marketized means.
- The power price marketization reform of the power system reform will have been completed by 2021, and then renewable energy will have a full access to the market.

Mandatory market policy

- In 2018, start the mandatory trading market for renewable energy power; in 2020, complete the construction of mandatory trading market, and significantly raise the proportion of the mandatory market every year compared with that under State Policy Scenario, for example, the proportion of renewable energy will be increased from 15% to 20-22% in 2025 for power purchase from the grid
- According to the supply scale the market can offer, establish a mandatory quota and trading market for biomass purification and gas supply in 2020-2030
- Completely establish a mandatory installation system for renewable energy heating for new buildings before 2020, and establish a mandatory renewable energy heating proportion system for industrial heat before 2025

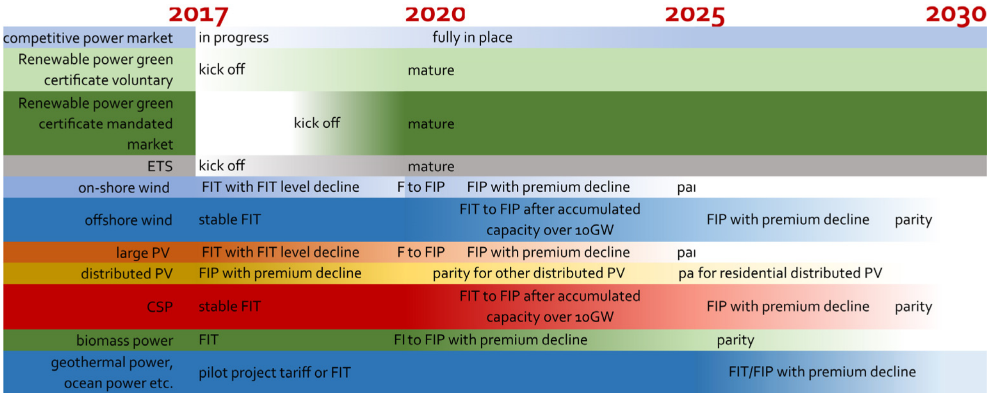
Policies on tax and fee

- Special financial funds are incorporated into Renewable Energy Development Fund for advanced technology research and development, demonstration, investment subsidy for new technology project and subsidy for new application mode, such as intelligent micro-grid system.
- Define the land utilization policies, refine standards for using applicable land, specify the standards for land requisition fee, compensation fee and annual utilization fee as soon as possible, and develop marginal land such as deserted land and land along highway and railway in renewable energy development according to standards for utilization of other land or improvement of used land, where standards for land requisition fee and utilization fee must reflect the actually avoidable cost.
- Larger-scale special financial funds are incorporated into Renewable Energy Development Fund for key supports in research and application of high-permeability grid system, in addition to advanced technology research and development, demonstration, investment subsidy for new technology project, and subsidy for new application mode (such as intelligent micro-grid system).

Financing policy

- For renewable energy policy projects confirmed by the State, such as PV poverty alleviation project), continuously arrange preferential credits for support.

Figure 16-14Roadmap for the transformation of renewable power tariff subsidy mechanism



	2017	2020	2025	2030
competitive power market	in progress	fully in place		
Renewable power green certificate voluntary	kick off	mature		
Renewable power green certificate mandated market	kick off	mature		
ETS	kick off	mature		
on-shore wind	FIT with FIT level decline	F to FIP FIP with premium decline	pai	
offshore wind	stable FIT	FIT to FIP after accumulated capacity over 10GW	FIP with premium decline parity	
large PV	FIT with FIT level decline	F to FIP FIP with premium decline	pai	
distributed PV	FIP with premium decline	parity for other distributed PV	pa for residential distributed PV	
CSP	stable FIT	FIT to FIP after accumulated capacity over 10GW	FIP with premium decline parity	
biomass power	FIT	FI to FIP with premium decline	parity	
geothermal power, ocean power etc.	pilot project tariff or FIT		FIT/FIP with premium decline	

17 Enabling wholesale power market for efficient integration of Renewable Energy

Inadequate economic signals and institutional arrangements are major reasons for today's high levels of wind, solar and hydroelectric curtailment and are obstacles to placing more wind and solar energy on the grid (RAP, 2016). Better price signals through the introduction of electricity markets is one important way to improve the situation. But market design strategies must also be adapted to high shares of variable renewable energy (VRE).The question of electricity market designis, therefore, closely linked with renewable energy.

17.1 Market design fundamentals

In this section, we introduce a few of the central elements in power market design along with the economic concepts underpinning their global proliferation. Next, we highlight the disparity between these central principles and the current market framework in China. Finally, we describe the on-going power market reform in China and assess the degree to which it addresses the key issues.

Key elements in efficient power markets[102]

Existing market designs show a wide variety of implementations across the world. This largely reflects different historic evolutions and preferences between countries. For example, market liberalisation in the United States was primarily driven by the need to integrate numerous regional utility companies and manage a multitude of transmission bottlenecks. By contrast, market liberalisation in Europe was driven by a desire to integrate larger electricity systems in member countries and facilitate trade between regions with their own well-meshed grids (IEA, 2016). Accordingly, US power markets are built around a central market and a single system operator. In Europe, system and market operation are separated. Market participants trade via a power exchange that specifies price, quantity and delivery times within a balancing area. Participants themselves decide which plant to operate. This arrangement is characterized by self-scheduling and self-dispatch.

Price dynamics in power systems

In theory, the price dynamics of a market primarily depend on economic fundamentals such as supply–demand balance and cost causation. For electricity, the physical nature of the product limits the ability to match supply and demand. Unlike most other market commodities, electricity must be generated and consumed concurrently. The high cost of electricity storage means that markets are hard pressed to coordinate production and consumption times. In each instance of operation, the grid's capacity to transport electricity is finite. Moreover, grid flows do not follow the typical price mechanisms

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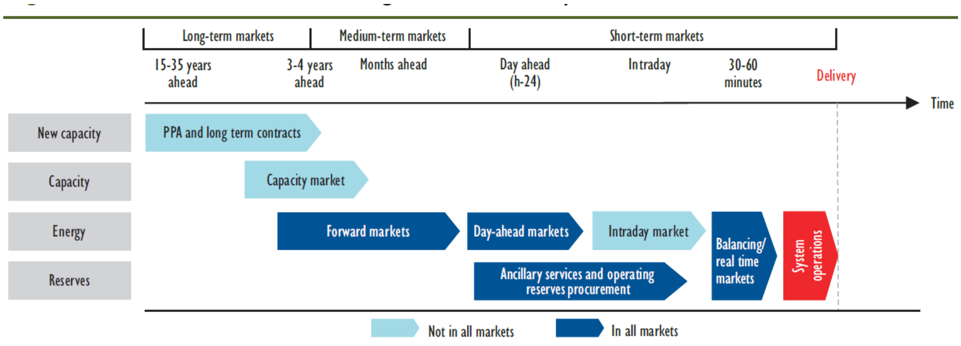
[102] This section is based on CE Delft and Microeconomix (2016): *Refining ShortTerm Electricity Markets to Enhance Flexibility. Study on behalf of Agora Energiewende*, p. 29 – 39.

governing commodity transport but physical laws. The limited amount of active control creates a risk of disequilibrium between supply and demand. In extreme cases, a market failure like this can lead to system collapse, unless auxiliary measures are in place to ensure reliability when the market is unable to. A hallmark of good market design, then, is the ability to balance the power system across regions and times.

Further complications can result from supply-side factors. Power plants generally require time to ramp up after shutting down for market clearing, while wind and solar generation varies with the weather. And market scheduling relies on forecasts whose accuracy increases only near time of operation. For markets to deliver valid price signals and drive optimal outcomes, they need to factor in these aspects. Short-term price dynamics are highly affected by market design, i.e. by the specific rules that govern the functioning of these markets. These include incentives for electricity producers or users to balance consumption ahead of time.[103]When markets are designed well, they encourage many players to participate in the market so that no one has sole power.

Finally, long-term power system efficiency requires markets to provide signals for advance investment in new capacity given its long lead times. Only then will it be possible to securitise long-term fixed asset investments in a way that does not impact the market's ability to operate optimally in the short-term. Other key aspects driving the long-term evolution of the power system are the degree to which market players must bear the inherent risks of the business, the degree to which such risks are socialised or otherwise re-appropriated through market design and policy framework and, finally, the opportunities for hedging residual risks. Asymmetries between technologies with regard to risk appropriation can also have a strong influence on the practical evolution of the capacity mix.

Figure 17-1Overview of different building blocks of electricity markets



Source: https://www.iea.org/publications/freepublications/publication/REPOWERINGMARKETS.pdf (p. 36)

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[103] This is largely lacking in China's current dispatch paradigm due to the nonexistence of short-term trading markets.

In practice, however, market design may diverge from the ideal depending, say, on operational requirements and balancing complexity. Some actions – e.g. scheduling too much generation at a security-constrained point on the transmission system, requiring the operator to re-dispatch the system – might increase total costs. Ideally, market prices should deter cost-causing actions and encourage cost-saving actions, but this can be difficult for market design to achieve.

It is critical to think about the different time-scales that are relevant for power systems, which range from future planning to real-time operations. Electricity markets should not be thought of as a single market but as a sequence of markets with different products. Figure shows the typical electricity power products along with their respective time scales.

When designing markets it is important to acknowledge the challenge of taking into account all aspects of electricity system planning and operation. Take the issue of reliability. Reliability is generally considered a public good since it benefits all customers, and one customer having it does not exclude others from having it. But reliability requires regulatory interventions to ensure efficient pricing and fair cost recovery. Also, short-term markets are not typically designed for the sole purpose of efficient system allocation. For example, system operators may be inclined to design the balance market (BM) in a way that ensures system reliability while paying less attention to balancing costs. This holds true for China as well, whose centralized scheduling system makes producers responsible for maintaining system balance and reliability. For instance, producers are expected to make large adjustments of 30% or even 50% of full load over short periods.

Efficient market principles

According to neo-classical economics, an efficient market follows three distinct theoretical principles when pooling resources:

- Marginal pricing principle
- Opportunity cost pricing principle
- No-arbitrage principle

Even if we relax the conditions for competitive market efficiency – limited market power, relative product homogeneity, rational expectations, etc. – the above principles must remain. Not adhering to them in any individual case would result in inefficient allocation. The principles are described in more detail below using China as an example.

Marginal pricing principle

Marginal pricing is a general economic principle that, under certain assumptions, leads to the maximization of social welfare and efficiency. The idea behind the principle is simple. If the price of a good or a service is set at its marginal cost/value for the society, then the individual market players will act efficiently:

- They will produce the good or service if the internal marginal cost is lower than or equal to the price.
- They will consume the good or service if the internal marginal benefit is higher than or equal to the price.

Producers have an incentive to keep their costs and their profit margins low, otherwise they risk pricing themselves out of the market and losing business to competitors. If prices follow the marginal pricing principle, then effective coordination between market participants is ensured, in the sense that social welfare is thereby maximised.

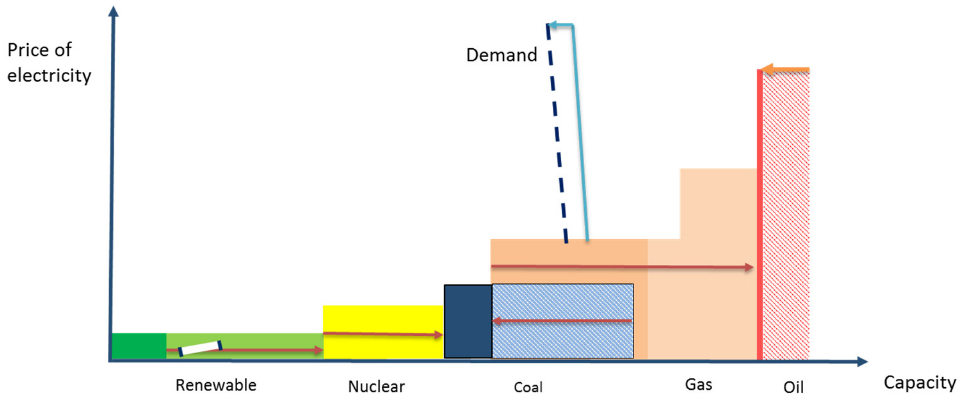
Opportunity cost pricing principle

The opportunity cost associated with the production of certain goods and services is the second theoretical principle to assess price dynamics. The general economic principle of opportunity cost pricing is as follows. Certain resources can be used to produce multiple goods or services. Efficient pricing for the optimal allocation of these resources needs to include the opportunity cost – i.e. the foregone benefit of not producing an alternative good or service with the same resources. The opportunity cost of producing a good affects the supply of the good, which in turn affects its price. That is, resources and money will tend to go elsewhere until the price of the respective good or service rises enough to make it more beneficial to forego all other uses. This maximizes the economically efficient use of resources.

No-arbitrage principle

The third theoretical principle by which to assess price dynamics is based on the no-arbitrage condition. According to this principle, the prices of perfect substitute products should be equal so that systematic arbitrage opportunities do not arise in efficient markets. It is also known as the law of one price.

Figure 17-2 Merit-order curve illustration



These three principles are fundamental for the power market design and the reason why nearly all power marketshave adopted marginal player pricing in a single unified market (such as the spot energy market) and why the ***merit-order curve*** (Figure) is applied for price formulation, market modeling and simulation.

These principles are largely lacking in China's power system today. In particular:

- In China, the power price is cost driven, but it is not market-value driven for all types of generation options. Moreover, the dispatch is not based on the marginal cost but on an informal *equal share* principle.
- Centralized scheduling still dominatesthe short term (one month or less), and the lack of transparent prices for system servicesdoes not reflect the opportunity cost. Onthe one hand, the value of the upward ancillary service is quite low due to overcapacity in the system, though several so-called *peak regulation plants* are under construction or in the planning stages.[104]On the other hand, the "downward" service (decreasing generation) is regarded as an obligation generally[105] and proper compensation does not take place.
- China's current market is far from beingintegrated. This is especially the case for long-distance electricity trading, e.g. from large-scale hydro stations in Yunnan, Sichuan and Hubei to coastal areas. The electricity price for the remote market is even lower than that absorbed in the local grid. This "double-track" approach – i.e. pricing based on two different regimes – violates the fundamental principles mentioned above. The market share of generation is based on a fixed yearlyplan, and the resulting inflexibility reduces economic efficiency.

To understand these aspects in the context of economic efficiency,we will summarize the above market principlesfor the power sector as well. In particular, we explore them in view of the rising share of renewables.

Key shortcomings ofthe current system

There are three key shortcomings in generation dispatch and one key shortcoming in transmission. These shortcomings create suboptimal outcomes by disincentivizing the use and development of power system flexibility.

The three generation shortcomings are as follows:

1. The annual generation plan guarantees minimum full load hours for coal power plants, an approach usedinall provinces, more or less. This paradigm has roots in China's planned economy.

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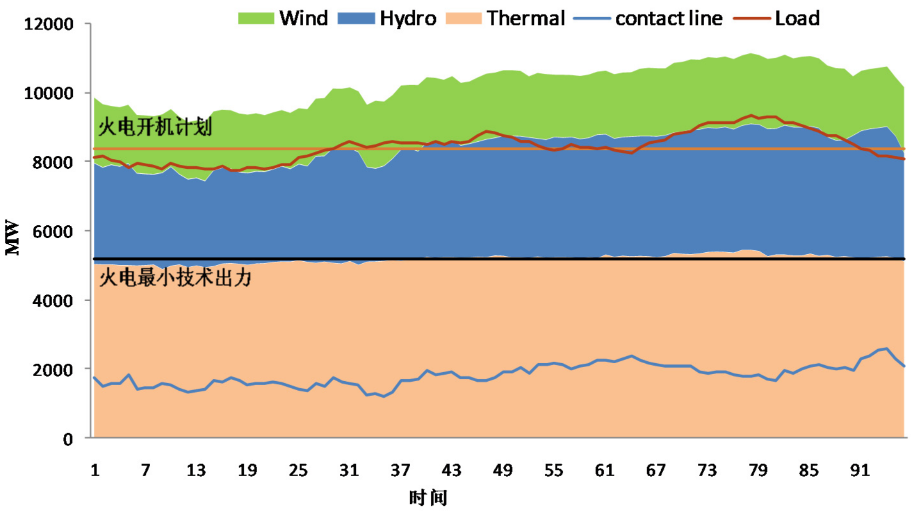
[104] See the case discussed in Shandong, http://www.sdeic.gov.cn/articles/ch01055/201702/6c765e04-6804-4326-ab0b-7cd7f49a0ee7.shtml.

[105] It has been noted that some cost remuneration was introduced in the Northeast regions to compensate units with deep generation reduction during low demand. Nevertheless, the benchmark for defining service volume and its cost is quite opaque due to the lack of short-term balance checking.

2. Due to technological and institutional limitations, thermal plants are unable to reduce output sufficiently (Figure), i.e. they remain far from the minimum output.
3. Finally, CHP plants have a social obligation to satisfy heat demand in winter. As a result, CHP plants must adhere to an increased minimum heat production. This takes priority over down regulation in order to accommodate wind or solar power. This market framework is not conducive for developing alternative heat generation or storage, which could alleviate the problem.

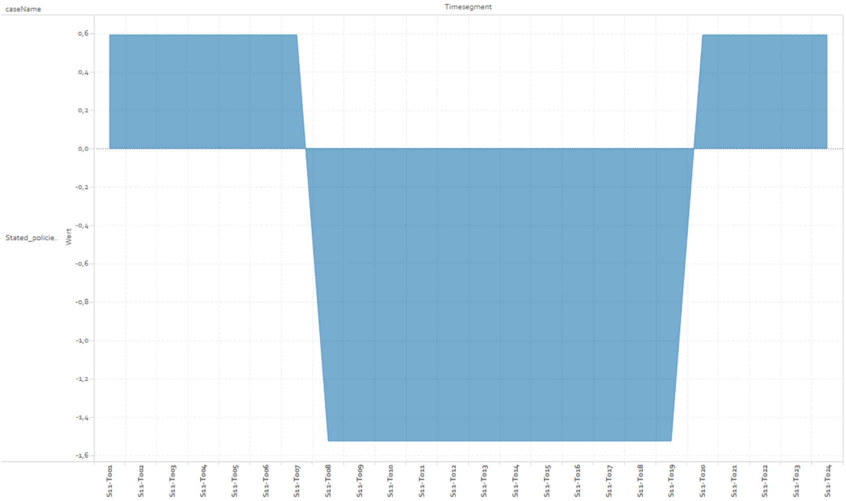
Figure 17-3 Baseload coal power during system operation in Gansu, China



Note: The contact line signifies imports and exports between Gansu and its neighbouring regions.

The shortcoming in the transmission system is that the operation of interconnectors and the integration of balancing areas are not based on market or price signals that modulate operation levels several times a day. Instead, the transmission system switches between two fixed levels of daily operation, and cannot incorporate short-term events like weather change or demand change (e.g. due to fluctuating factory production). Moreover, the system has only two seasonal models, one for summer and another for winter.

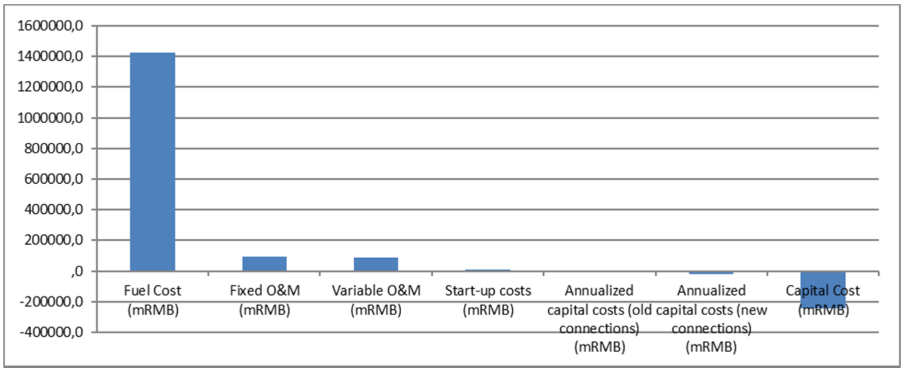
Figure 17-4 Trade balance (hourly values of a single day) from Henan to Hebei in 2016



(with inflexible interconnector use)

EDO simulations show that maintaining these imperfections with the same renewable share would mean an incremental aggregated system cost of at least 6% from 2016–2050, amounting to some1 trillion Yuan. Figure shows the incremental costs of a *market failure* variant of the stated policies scenario. The *market failure* variant assumes that the market reform results do not improve over time. The variant maintains constraints such as guaranteed full-load hours, inflexible dispatch, limited demand response, etc. Basically, it retains the 2016 reform assumptions discussed in part 2. The market failure variant leads to a 6%increase in the costs of the power supply (including both power generation and transmission systems), even though grid investment is lower. Particularly expensive in the market failure scenario are the fuel costs, which arise from the added use of coal power plants.

Figure17-5 Comparison of system costsin the market failure scenario relative to the stated policies scenario, 2016–2050



A well-operating power market would need to eliminate the effects of an inflexible, planned operational paradigm for more economic and environmental efficiency.

Highlights from the latest round of discussions about power market reform

In March 2015, China published on official communiqué on power market reform. The so-called Document No.9 began a renewed push to establish competitive wholesale and retail electricity markets, especially for industrial customers. The policy is supported by several market pilot projects in multiple provinces.

Now, two years later, pilot projects continue in some provinces, including Guangdong and Zhejiang, and have ended in Yunnan and most of the others.

Below we summarize the progress so far and recommend some key policy actions.

A clear benchmark is needed to evaluate China's progress towards creating an efficient and well-functioning power sector. The experience of US and European countries could provide such a benchmark. Since the end of the 1990s, countries in Europe and regions in the US have introduced a competitive wholesale market, regulation governing third-party access to transmission and distribution networks, legal separation of retail businesses, retailer choice for all customers, unbundling of transmission and distribution businesses from the rest of the sector, regulation for cross-border trading and independent regulatory authorities (Pollitt and Anaya, 2016). The process has been slow and European countries have moved at very different speeds, but overall progress has been remarkable.

Document No.9 and subsequent supporting materials have identified five main tasks covering electricity price, the power trading system, wholesale market design, the power grid and governmental supervision. Table describes these tasks and provides brief evaluations of their progress, labelling each change as either substantive (sub.), procedural (proc.) or symbolic (sym). It also indicates the associated risks.

Table 17-1 The substantive, procedural and symbolic significance of power sector reforms

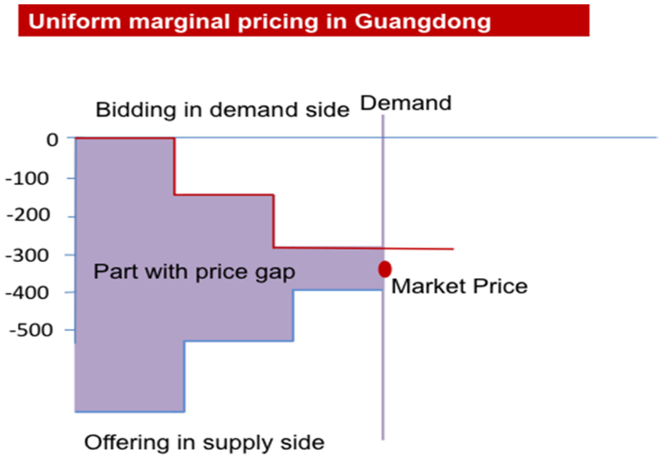
No.	Item	Responsible body	Sub.	Proc.	Sym	Risks
1	Independent transmission and distribution (T&D) pricing reform	Price department of NDRC	√			Information, capacity, competence asymmetries between grid companies and regulators.
2	Long- and short-term power market development	Market regulation department of NEA; economic operation department of NDRC		(√)	√	Rules and principles are not harmonized across provinces.
3	Power trading infrastructure (exchange) development	Law department of NEA;reform department of NDRC			√	Banner change;mostly dominated by existing grid companies. (A few regions such as Chongqing are exceptions.)
4	Deregulation of the yearly generation and consumption	Economic operation department of NDRC; market regulation department of NEA		√		Relies on the discretion of local government and the transition process to achieve full market volume.
5	Reform of power retail (adds more market players)	Reform department of NDRC; power department of NEA	√			Market power of the grid company affects grid assets, trade accounting and dispatch.

Source: Authors' compilation.

Accounting for separated transmission and distribution prices (T & D price), and increasing the number of market players in the retail market could be considered "substantive" steps towards a working market environment. Grid fees can be monopolized and regulated, though the generation and retail sides are meant to be competitive.

Other changes are less significant save for some procedural meaning in market-based trading,[106] especially in Guangdong province. These changes still mostly focus on monthly contracts, but these fail to reflect the real-time variation of supply and demand. Its price clearing mechanism uses quasi-marginal pricing based on consumer bids and supplier offers (Figure). The hardware and software transition from such systems to short-term markets such as the day-ahead market stands to be seamless.

Figure 17-6 Pricing approach in the Guangdong power reform pilot project



Source: Revised based figures from South China University of Technology, 10 May2017

17.2 Power energy market and ancillary service

Market requirements when share of renewables is high

The integration of stochastic, variable renewables into the conventional, fossil-fuel-dominated power system requires a paradigm shift. When the share of variable renewables is high, the required amount of operating reserves in creases (especially for slower-acting reserves). This can increase the demand for ancillary services and, by extension, power prices. Nordic countries have found improved wind and solar forecasting and the increased integration of electricity systems to reduce the cost of and requirements for ancillary

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[106] 900 retail companies were registered by the end 2016, but none marketed electricity.

services. There, the need for balancing and frequency reserves has remained mostly stable even though the share of renewables has increased.[107]

Dealing with fluctuations in supply and demand over periods ranging from minutes to hours generally entails higher levels of system flexibility (IEA, 2014; IEA, 2017), which the market may or may not incentivize. Moreover, the variability of wind and solar power leads to higher fuel costs during windy and sunny periods. Known as the merit-order effect, this phenomenon can challenge the economics of existing power plants. While such signals may reflect overcapacity (IEA, 2014), they can also pose a risk to supply security.

To ensure that the system has adequate levels of supply, additional regulatory and market design measures such as capacity remuneration mechanisms (CRMs) may be needed (Joskow, 2008). Germany and Denmark have introduced strategic reserves to deal with the issue. Plants in the reserve do not participate in the market. Only if demand and supply cannot be matched does the TSO put plant capacity out to tender. Price caps to ensure high prices minimize distortions on short-term markets.

In the long term, generation capacity will adapt to new operating patterns. VREs require fewer plants running at a constant level around the clock (baseload) and more plants operating flexibly. The difference can generally be represented by the "residual duration load curve" (RDLC), which involves subtracting variable renewable output from net load.

VREs have three main effects on the power system. First, they reduce the full-load hours of dispatchable power plants for intermediate and baseload plants. This reduces the annual and life-cycle generation per capacity of those plants, thereby increasing the average operating costs per MWh for generators in the residual system. For these generators to remain competitive, the prices need to be higher on average during the fewer hours they are dispatched. This may spur competition for generation in these hours, which improves the competitive position for mid-merit units, peak units and storage. Long-run system will use less baseload and move towards more flexible generation.

Second, VREs barely reduce the need for backup capacity, especially during peak load times, when capacity credit is low. More renewable capacity installations would reduce the need for more capacity, further decreasing the system utilization rate (generator and grid). The integration of balancing areas can reduce the need for reserves through common dimensioning and sharing.

Third, at high shares, VRE generation leads to overproduction and may need to be curtailed. Hence, the effective capacity of VREs declines and the specific per-energy costs of VREs increase.

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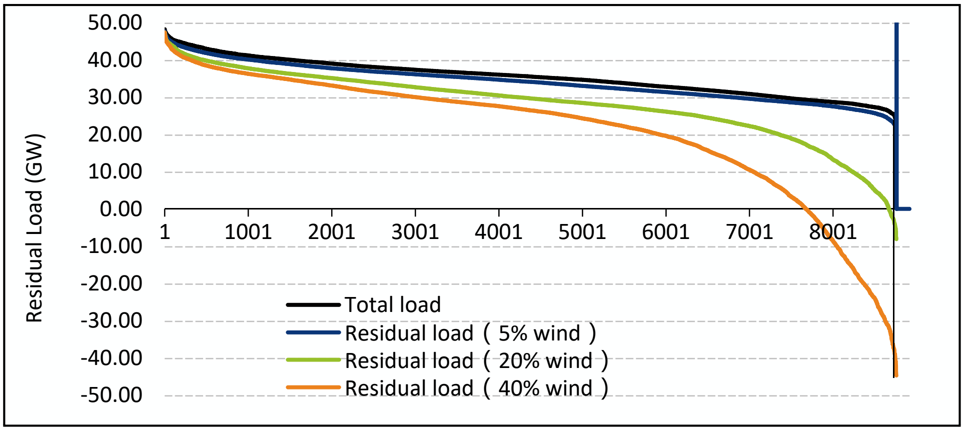
[107] See http://www.energinet.dk/EN/KLIMA-OG-MILJOE/the-Danish-windcase/Sider/Den-danske-vindcase.aspx

Figure 17-7 Diminishing baseload in residual load curve (Jing-Jin-Tang power grid)

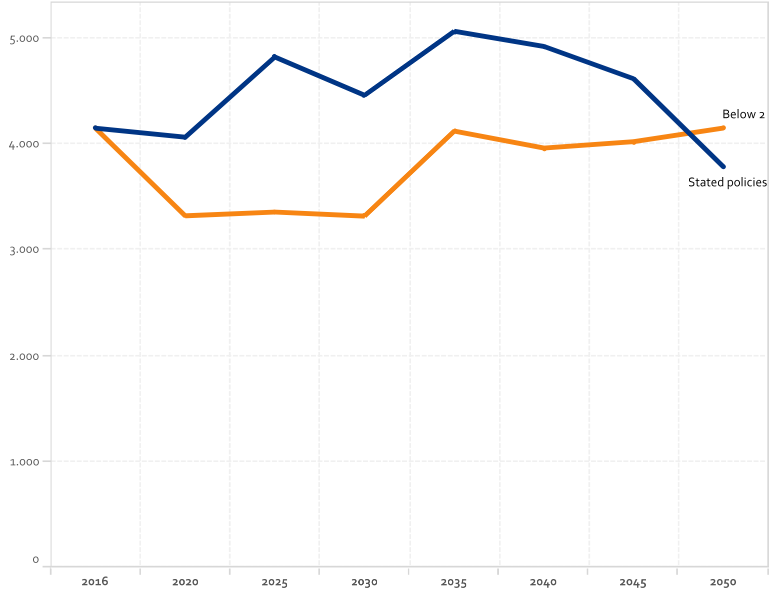


Source: EDO modelling output

These three effects of renewables on the power system constitute a "profile cost". A well-designed power market differentiates the revenues paid to VRE generators and the revenues paid to dispatchable generation. Policies decide to which degree these costs are socialized or directly assigned to the renewable generator. But market design can penalize revenues for renewable generators that operate in a way that increases the use of flexible resources (e.g., poor forecasting and scheduling), and that rewards actions that decrease reliance on dispatchable generators (e.g. renewable generators designed with energy storage and advanced power systems). The improved use of the electricity grid and the demand-side response can help lower the system impact of VREs. Policies to enhance system flexibility and the likelihood of market failures (split incentives, lack of information, etc.) might be needed.

EDO modelling shows that once China solves its overcapacity problem its coal-fired power fleet will be able to operate around 4500 hours per year. But when renewable shares are high – using CCS to alleviate the tightness of CO2 constraints in the 2-degree scenario – the average annual operating hours of coal power could be as low as 4000, and the system baseload becomes less relative to the case when renewable shares are low.

Figure 17-8 Full load hours for coal power plants in the two central scenarios using EDO modelling



Spot energy market with long-term contracts

Spot markets reward generators for matching supply and demand several hours to minutes ahead of real time. Typically involving day-ahead, intra-day and balancing markets, this incentivises generators to adjust their position based on the state of the power system and their own operating situation. Longer-term markets – such as monthly or yearly contract markets – financially hedge generators and loads (Plitt, 2017). A spot market provides the basic price signal around which all futures prices are determined. In practice, the day-ahead spot price serves as the reference point for the balancing and operation plan used by system operators.

Short-term spot market design can solve problems such as market entry, continuous trading and market clearing (marginal or pay-as-bid). In practice, multiple time scale products exist in wholesale markets in Europe and in the US, and they differ in several regards: zonal/nodal pricing, balance area coupling, product timelines and product attributes. The centralised pool model (see above) integrates imbalance pricing, congestion management and spot market ancillary services. The decentralised model requires the separate operation of spot-markets and near-day markets.

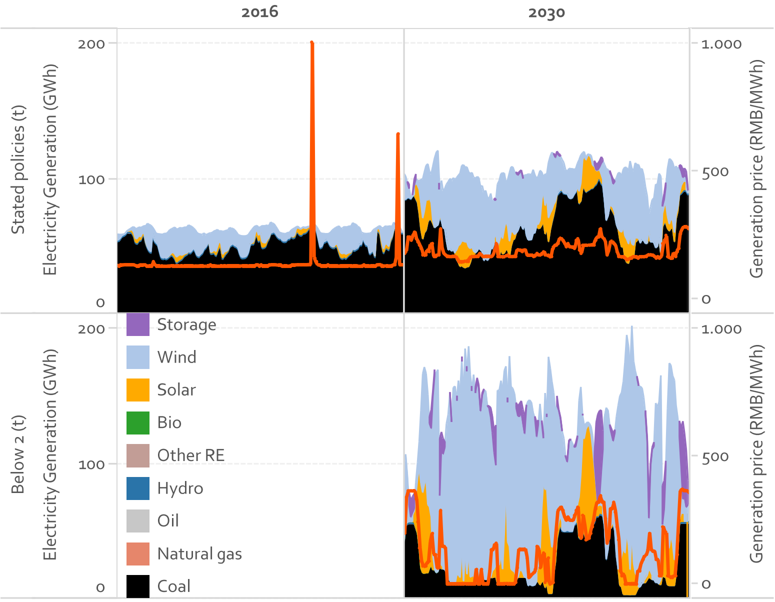
In the US, wholesale power markets – those run by independent transmission organizations and traditional monopoly utilities – are diverse and evolving. The ability to manage higher grid penetrations of variable renewable resources has been part of that evolution. But these wholesale power markets mostly follow the key principles mentioned above. And they use sophisticated schemes to couple the financial level with the physical level while putting a premium on real-time cost minimization. Typically, they use security-constrained economic dispatch to achieve these results.

In Europe, the market is more of a bottom-up process, but the EU market reform instituted the principles of free and non-discriminatory access across the EU single market. The creation of well-functioning, coordinated, harmonized and interconnected power markets in Europe involves balancing financial and physical energy markets with day-ahead, intraday and real-time trading.

Thanks to market liberalization, Europe and the US continue to learn how to balance common market principles with the need for flexible market models. This is where China has a real opportunity to jump ahead. Learning from international experiences, China can develop its core market principles and target models at an earlier stage in the power market reform process.

One critical lesson is that the short-term market should be truly short and fine grained. Several US markets rely on 5-minute intervals for intra-day trading, while European balancing markets have ramping times of 2–30 minutes and intraday gate closure times from 0–60 minutes before operation and an imbalance settlement period between 10 and 60 minutes (though in the future this is supposed to drop to 15 minutes). At a bare minimum, an hourly day-ahead market is required to capture the rapidly changing supply and demand (which is especially volatile when the share of VREs is high). Figure 17-9 Illustrates the hourly price volatility for Inner Mongolia from 2016 to 2030 in the below-2-degrees scenario.

Figure 17-9 Hourly generation and price in Inner Mongolia week 11 of EDO modelling



In our view, this target model must recognize the following points:

- There is a need for well-functioning spot markets that define the price reference for balancing and operational.
- The true benefit of efficiency lies in the interconnection of areas with different resource endowments; this requires that markets be broad, technology-neutraland homogenous.
- The market should be inclusive and deep, and have low barriers to entry such that all resources that are able to provide energy and services to the system can do so.
- The short-term spot and balancing markets should serve as the reference for the current value of electricity and that the long-term securitisation of investments should be ensured through other mechanisms such as indexed financial derivatives on spot market prices, auctioned long-term PPAs, etc. But these mechanisms should not tie generation to physical deliveries; market players must stay motivated to make bids based on short-run marginal costs regardless of their long-term positions.

Balance ancillary service on the energy market

Ancillary services are services that help deliver capacity and energy from resources to loads while ensuring continued electric service. Despite the similar function, these services differ significantly between the US, European and Chinese markets (Table 17-2) In the US, the Federal Energy Regulatory Commission's (FERC) has required that the transmission provider offer six ancillary services since 1997, whenit issued Order No. 888 (FERC 1996). Although FERC's requirement for ancillary services is consistent across all wholesale markets, there are substantial differences in how they are procured. Traditional monopoly utilities acquire and pay for ancillary services based on FERC-approved rate schedules. RTOs (regional transmission organizations, which are often exchangeable with ISOs) use competitive markets to procure capacity for most ancillary services. The RTO determines how many MW of each service needs to be held in reserve for each operating hour. The cost of reserving the capacity is allocated to load-serving entities (such as power plants), although load-serving entities often have the option of providing part of their ancillary service obligation themselves. More recently, market systems have improved so that the RTO's various ancillary service procurements can be co-optimized with day-ahead energy procurements.

Table 17-2 Types of balance ancillary service in typical ENTSO-E, US and China markets

Ancillary service Type	*US*	*ENTSO-E*	*China*
Frequency support	Regulation load following (non) spinning reserve	Frequency containment reserve (FCR) (<5, 10 or 30s) Frequency restoration reserve (FRR) (<15 min)	Primary AGC secondary
Operating reserve	Non-spinning reserve	Reserve RR (15 min to hours)	Peak regulation backup
Supplemental reserve	Supplemental reserve	(Strategic) reserve	

Source:http://orbit.dtu.dk/files/57657061/Ancillary_services.pdf;
Personal communication with Ella Chou (NERC 2014), NREL.
CE Delft and Microeconomix (2016): Refining short-term electricity markets to enhance flexibility. Study for Agora Energiewende
http://www.efchina.org/Attachments/Report/reports-20120717-zh/reports-20120717-zh

While the technical characteristics of different balancing power types are largely harmonized throughout the European Network of Transmission System Operators for Electricity (ENTSO-E), the balancing power market design is national despite an emergent coupling trend. A wide range of institutional setups exist: uncompensated supply obligation for generators, regulated or capped prices, mandatory offers by generators and competitive voluntary bidding (ENTSO-E 2015). While almost all electricity energy prices feature marginal pricing, pay-as-bid pricing is common in balancing power markets. In contrast to wholesale electricity markets, the balancing power is a single-buyer market exclusively for the TSO. The main types are frequency containment reserves (automatic and local), frequency restoration reserves (automatic or manual, centrally coordinated) and replacement reserves (manual).

So far, China's coal-based power generation system has minimised the need for formal ancillary services markets. There are some payments to generators for system support (voltage support or reactive power), though generally no formal payment mechanism exists for ancillary services.

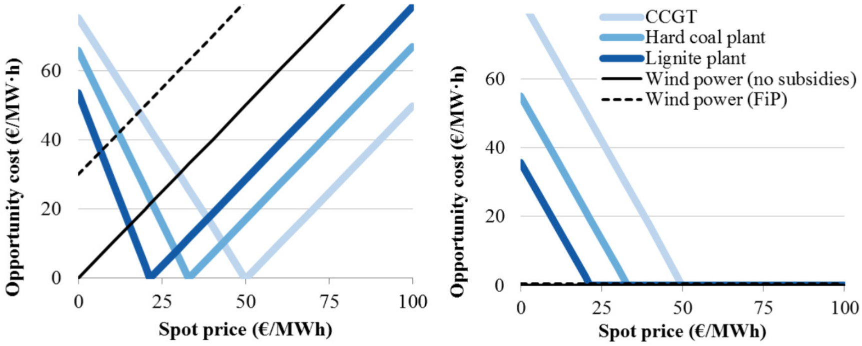
If power dispatch were to be reformed in China, the lack of formal mechanisms for procuring ancillary services would be an issue because some plants that are needed for ancillary services might be shutdown due to lack of competitiveness in the wholesale energy market. In all likelihood, the reform of dispatch would require the reform of ancillary services payments.

The main problem in China's power dispatch is not the lack of ancillary service but how the ancillary service is measured and remunerated. Commonly, ancillary service demand on the energy market is a delta to the benchmark (e.g. the power plant commitment), but China's system is different. All the market players have balancing obligations, while the system operator is responsible for the real-time balance and the residue load (due, say, to renewable and load forecast error and unscheduled fossil fuel plant outages). Ancillary service quantification and its associated costs should be explicitly defined and professionally supplied. The reform mechanisms should be flexible enough to allow non-traditional resources (demand response, variable renewables, large-scale batteries) to compete for future ancillary services.

The time scale used by power reform pilots in several Chinese provinces is so large (month-ahead) that ancillary services cannot be clearly defined, and the dispatch pattern is opaque. Spot market-based dispatch schedules must be moved closer to the time of operation to provide a reference quantity and price point for buying and selling ancillary services.

As the share of variable renewable power generation rises in the future, the power system's need for ancillary services that support network frequency, voltage, etc. will change. Fast frequency response (for synthetic inertia), ramping margin services and dynamic voltage control will be needed for more flexibility and faster response times. But other options are available for diminishing this increased need, such as moving from reactive to active reserve management.

Figure 17-10 Opportunity cost of wind providing balance service



Source: Hirth Lion, Hirth-Ziegenhagen-2015-Balancing-Power-Variable-Renewables-Links.pdf.

Note: The graph on the left shows upward balance service ; the graph on the right, downward balance service.

At the same time, market opportunities will emerge for wind and solar PV technology to deliver the needed grid services. Renewable generators can ramp down only when they produce electricity, although the opportunity cost is high. To ramp up, they need to be operated below their potential maximum output, which requires that some generation be curtailed. Although they can technically supply positive and negative reserves, they are economically better suited for downward balancing.

Hirth & Ziegenhagen (2015) identified the opportunity costs of renewables in the balance market over different market prices. At low spot prices, the opportunity costs of balancing reserve from thermal plants become positive. During windy and sunny hours, VRE generation depresses the spot price, driving up the opportunity costs of negative balancing power from thermal plants. In other words, the price of thermal generation increases when VREs are plentiful. During these times, it would be more efficient to use VREs for downward balancing.

17.3 Linking wholesale and retail: Enabling competition, DSR and consumer participation

Retail competition

Electricity retail choice allows end-use customers to buy electricity from competitive retail suppliers. The academic debate on retail competition has generally been of a qualitative nature, though there have been some econometric attempts aimed at examining consumer behaviour and at measuring the impact of retail competition on final prices (Concettini and Creti, 2013).

Retail electricity choice in the United States allows end-use customers (industrial, commercial and residential customers) to buy electricity from

competitive retail suppliers. As of 2017, 13 U.S. states and the District of Columbia have fully restructured retail electricity markets. Some states suspended access to retail electricity choice after the California power crisis of 2000–2001

(Pfeifenberger, 2016). While residential customer participation rates are low in most of the states with retail electricity choice, a significant number of industrial and commercial customers have switched to competitive service options (EIA, 2012).

The price effect of enhanced competition is difficult to measure because, among other things, the rates in retail choice states vary with respect to time, location, on- and off-peak conditions, fuel prices, retail services and other factors. This makes the "counter-factual" hard to identify. Implementing retail choice does impose some new costs, however. These include new billing procedures and metering that are compatible with retail services (Morey and Kirsh, 2016). Average retail prices of electricity per kilowatt-hour have been mixed overall, but in the three largest states with the most retail competition (Texas, Pennsylvania and New York) rates increased less than the national average between 2001 and 2017 (EIA, Forms EIA-861 and EIA-826). Nevertheless, some scholars argue that, though restructuring has brought considerable efficiency improvement at the generation level, it has not realized price reductions due to cost shifting, which ensures that utilities can recover their stranded asset costs as part of the transition (Borenstein and Bushnell, 2015).

A central issue in the restructuring of the U.S. power industry has been whether competition should be restricted to the wholesale power market or extend fully to the retail side (Bohi and Palmer, 1996). This debate arises from the fact that, while the benefits of wholesale restructuring are fairly concrete, quantifying the potential gain from retail electricity choice has been somewhat elusive. In general, researchers have shown that with an open retail market individual consumer preferences are more likely to be served, the range of products and services offered would be greater, and innovations would happen faster. In the wholesale-only market, transaction costs are likely to be lower and investment in transmission capacity is more likely to occur at a socially desirable level. But realizing the full benefits of retail electricity choice depends on the competitiveness of the retail market (Bohi and Palmer, 1996).

In Europe, liberalization reforms have allowed new firms to enter the market. The number of "main" retailers (retailers are considered "main" if they sell at least 5 % of total national electricity consumption) have hovered around 100for several years now.

Figure shows the number of main electricity retailers and their cumulative market shares for all EU Member States plus Norway, Turkey, Bosnia, Herzegovina, Serbia, Montenegro and FYR of Macedonia in 2015. The remaining market – populated by minor retail companies with a coverage of less than 5 % – is the largest in Sweden (62 %) and in Italy (59 %). The market for "minor" retail companies is below 25 % in 16 out of the 25 EU countries that reported this indicator.

On the consumer side, the ACER Retail Database (2016)[108]showed that in 2015, switching rates increased for household consumers in both electricity and gas markets. With an average external switching rate of 6.4% in electricity markets, switching rates could still be seen as moderate. The best performing European retail energy markets – Great Britain and the Netherlands – are moderately concentrated, fully liberalised and have relatively high switching rates.

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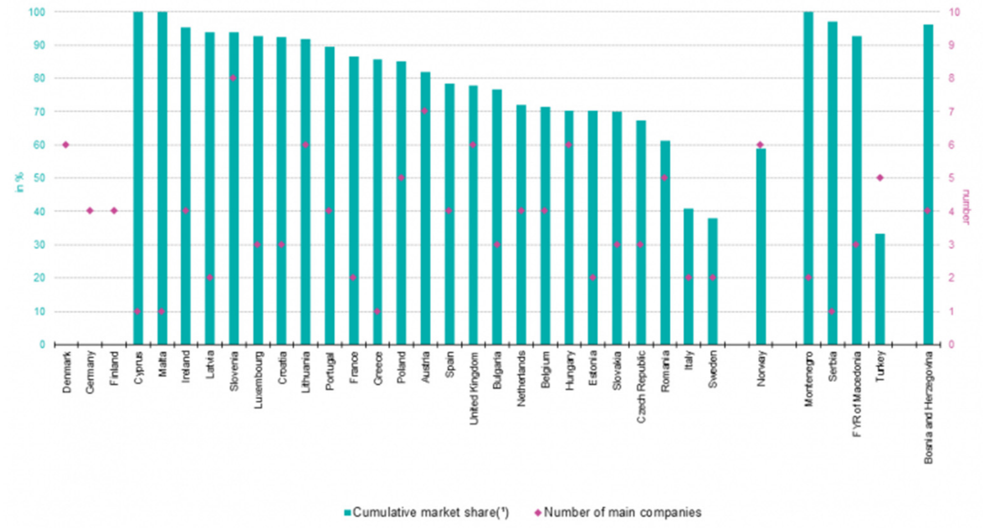
[108] See http://www.acer.europa.eu/official_documents/acts_of_the_agency/publication/acer%20market%20monitoring%20report%202015%20-%20electricity%20and%20gas%20retail%20markets.pdf

Figure 17-11 Number of main electricity retailers and their cumulative market share in 2015, Europe



Note: retailers are considered as "main" if they sell at least 5% of the total national electricity consumption.
(¹) data not available for Denmark, Germany and Finland

Source: Eurostat (This data is not yet available in the Eurostat dissemination database)

Source: Authors' elaboration of Eurostat data.

While retail choice may not have produced the price reductions that proponents initially envisioned, it has evolved into an important tool for promoting customer choice when using renewable resources for electricity. Also, it can leave the consumer exposed to the price volatility of the wholesale market, and make the demand response more feasible and incentive-based. This may lead to the creation of many novel technology applications and business modes, especially for many small enterprises and individuals (prosumers). These are detailed in the next section.

Price signals needed for increasing scale of DSR

Efficient market design and competitive retail markets are a key measure for enabling demand response. They make sure that markets generate price signals and induce behavioural changes in the power consumer. Using demand-side-response (DSR) with metering by the hour or less, consumers can fully utilise low wholesale prices when wind and PV feed-in levels are high.

In the context of renewable expansion, several measures can effectively reduce the need to rely on generator flexibility by increasing the opportunity for demand to respond in real time to variations in supply. The key to accessing this potential is to offer dynamic pricing (preferably in real time) to those wishing to participate and to remove barriers for demand-side participation in long-term, day-ahead, intra-day and balancing markets. In the US and

European energy markets, it has long been possible for large industrial customers to participate directly, first through interruptible rate tariffs and more recently through participation in ancillary service markets.

In the New England power market in the US, 16% of meters are advanced meters (about 1.4 million). The ISO has implemented payment-based programs for two types of demand resources (passive and active). Potential peak reduction could be as high as 11% of peak demand. Fullintegration of demand response with wholesale electricity markets will be finalised by June 1, 2018, at which point these resources will be able to participate in the energy, capacity and reserve markets. The deployment of greater amounts of advanced metering infrastructure and time-of-use rates can lead to the further proliferation of demand response.

All US and British markets in the table below have a capacity mechanism or a direct DR Program. In Germany, DR is usually on the spot market and only to some degree on the reserve/balancing market, but it is difficult to measure. Potentially, the total level could be as high as 4% to 20% (EU, 2016).

Table 17-3 DSR as a share of peak demand in European and US markets

Demand participation in wholesale markets	**Germany**	**Denmark**	**US NE**	**Texas ERCOT**	**Great Britain national grid**	**US PJM**
DSR as % of peak	No capacity mechanism; estimated as 4%–5%	9% (mainly electric boilers)	11%	3.20%	3.60%	9.10%

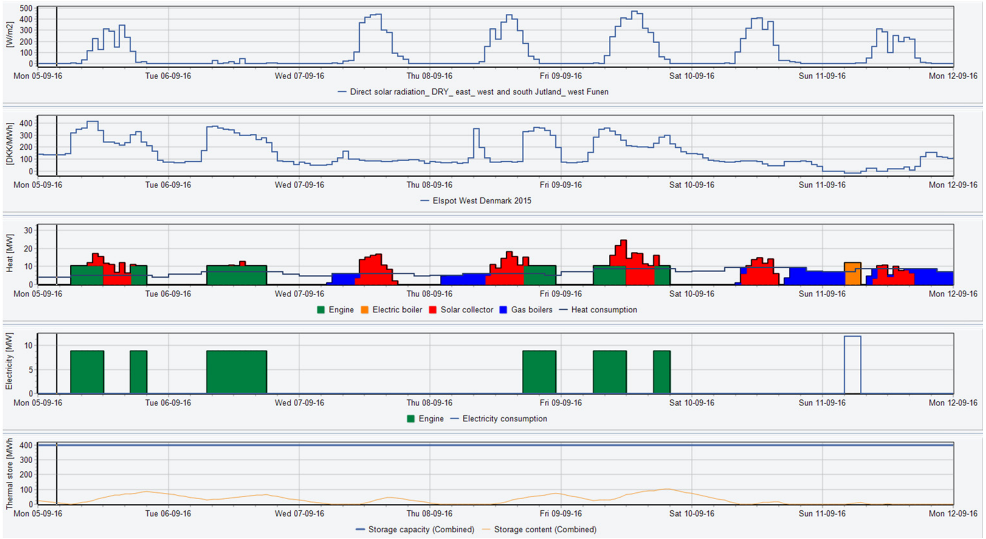
Source: Khalid et al (2016), Plitt et al. (2017), Coutu (2017), EU (2016); https://www.energinet.dk/Analyse-og-Forskning/Analyseforudsaetninger/Analyseforudsaetninger-2017; author's compilation

Pushing this direct market participation model to residential and small commercial customers, a larger and more diverse pool, is challenging on a number of levels, including the fact that in most cases these customers have neither the capacity nor the willingness to respond reliably or bindingly in real time.

To access this potential, it is essential that energy markets be opened to demand aggregation, in which consumption by individual consumers – or by individual loads at consumers' premises – is managed under contract to a single service provider in return for whatever form of compensation the aggregator and consumers agree to. The aggregator then sells the equivalent amount of energy production to the market. Aggregators can and do use demand response to supply both various balancing services – a source of flexibility that will be discussed below – and capacity value, which often can successfully compete with the cost of an equivalent amount of generating capacity.

Another form of demand response can be achieved by making combined heat and power facilities more flexible. This typically involves the incorporation of thermal energy storage systems so that provision of heating (or cooling) can be physically decoupled from the operation of the CHP plant to produce electricity when needed. The same application of distributed energy storage (e.g. heat storage) is technically feasible and can be applied inexpensively to thermal appliances at customer premises. This is yet another source of demand flexibility that could be dispatched to meet the needs of the power system.

Figure 17-12Flexible use of CHP plants, power-to-heating and storage in Denmark



Source: https://www.emd.dk/energypro/project-examples/danish-cogeneration-plant-and- solar-collectors-in-separate-sites/.

Note: The top graph shows solar radiation at every hour for the given region. Radiation is used to calculate heat production from the solar collectors. The second graph shows the electricity price in West Denmark every hour. The third graph shows the heat production of different units and the total heat demand. The fourth graph shows electricity production and consumption. The last graph shows storage capacity and content. The CHP (in green) is operated at hours with high electricity prices and the electric boiler (in orange) at hours with low electricity prices. The solar collectors (in red) produce as much as possible and the boilers (in blue) cover the rest of the heat demand.

17.4 Power market and regulation: Competitiveness and sustained RE expansion

From cost to value[109]

The generation cost of various technology options is most commonly expressed as the levelised cost of electricity (LCOE). LCOE, as it is commonly defined, is a measure of the revenue that would be needed to recover the cost of building and operating a power plant. It is calculated by adding up all the plant-level costs (investment, fuel, emissions, operation, maintenance, etc.) and dividing them by the amount of electricity the plant will produce. Costs that are incurred at different points in time (such as the up-front costs of building the plant and operational costs in later years) are made comparable by way of a net present value calculation, which "levelises" them over the economic lifetime of the plant.

But LCOE does not take into account the when, where and how of power generation. The when refers to the temporal profile of power generation that can be achieved; the where refers to the location of the power plant; and the how refers to the implications of generation technology on the system. Whenever generation technologies differ in the when, where and how, LCOE is no longer sufficient for comparison and can produce misleading results. A comparison based only on LCOE implicitly assumes that the electricity generated from different sources has the same value on average.

The value of electricity depends on when and where it is generated, particularly in a power system with a high share of VREs. During certain times, an abundance of generation can coincide with relatively low demand; in such cases, the value of electricity is low. Conversely, when little generation is available and demand is high, the value of electricity is high. Considering the value of electricity for the overall system opens a new perspective on the challenge of VRE integration and power system transformation.

System value (SV) is defined as the net benefit arising from the addition of a given power generation technology. While the conceptual framework applies to all power generation technologies, the focus here is on wind and solar power plants. SV is determined by the interplay of positive and negative effects arising from the additional technology. To specifically calculate the technology's SV, one must first specify which factors need to be considered. For example, a calculation may or may not include positive externalities of technologies that do not rely on fuel whose prices experience significant fluctuations.

On the positive side are all those factors included in the assessment that lead to cost reductions. These include reduced fuel costs, reduced CO_2 and other pollutant emission costs, a reduced need for other generation capacity and possibly a reduced need for grid usage. On the negative side are increases in certain costs, such as higher costs for cycling conventional power plants and for additional grid infrastructure.

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[109] This section borrows from IEA, 2016: Next generation wind and solar power: From cost to value, available at https://www.iea.org/publications/freepublications/publication/next-generation-wind-and-solar-power.html.

SV supplements the information provided by classicalgeneration costs metrics such as LCOE. It captures the effects that additional generation has on the remaining power system. While LCOE indicates how much one must pay for a certain technology, SV describes its net effects on the system.

Calculating the SV for balancing a technology requires making several assumptions about, say, fuel prices and CO2 prices.[110] It may also require modelling tools that can compare costs between different scenarios. It is possible to estimate certain SV components by analysing actual market data. This makes it easy to obtain data in most regions, but it requires a very careful interpretation of the results. Only in the – theoretical – case that markets accurately price all relevant externalities, remunerate all benefits and charge all costs do market prices fully reflect SV.

The degree to which this occurs in practice depends on many factors. For example, assessing SV on the basis of spot-market revenues – see the analysis below for onshore wind – may not capture all relevant impacts on grid infrastructure if the same price obtains over large geographic regions. However, even partial SV information can provide critical insights for policy and market design.

A high SV indicates a good match between what a technology provides and what the power system needs. For example, when a new VRE power plant generates during times of high electricity prices, the favourable situation is reflected in a high SV for the plant. In well-designed power markets, a generator receives an above-average market price for electricity during these times.

The SV perspective provides crucial information above and beyond generation costs. Indeed, comparing LCOE and SV provides critical information for policy makers and other power system stakeholders. When SV is higher than VRE's generation costs, additional VRE capacity helps reduce the total cost of the power system.

As the share of VRE generation increases in power systems, the variability of VRE generation and other adverse effects can lead to a drop in overall SV. For example, at the onset of deployment, solar PV often generates at times of fairly high demand. This translates into a high market value as long as its share is low. But as more PV capacity is added to the system, all PV systems tend to generate at the same time. This means that when PV capacity is generating, there is an abundance of electricity. This leads to lower prices when it is sunny and, in turn, a lower market value for PV-generated electricity than that of a dispatchable generator. The exact magnitude of the effect depends on the technology and the specific system conditions. The principle itself, however, is universal: *the economic challenge of system integration is reflected in the declining value of wind and solar power*.

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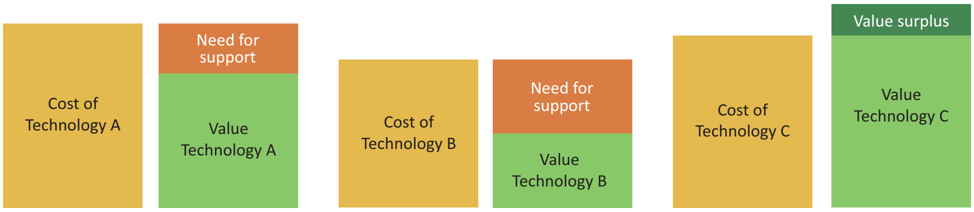
[110] System value can also include technical capabilities such as dynamic voltage, inertia, re-active power and short-circuit effect.

The reason for the decline in value is the lack of flexibility in the power system and in the energy system generally, combined with the variability of wind and solar power. The aim of power system transformation is to deploy a comprehensive package of measures that make the overall system more flexible. In a flexible power system, SV for VRE remains high even at high penetration levels.[111]

Introducing the concept of system value produces deeper insights into appropriate renewable energy policy design. Policy priorities during the early days of VRE deployment were not focussed on system integration. Instead, they focussed on maximising deployment as quickly as possible and reducing LCOE as rapidly as possible. But this approach does not suffice at higher shares of VRE. For example, a feed-in-tariff provides no incentive to seek wind resources that have a good match with supply and that are located close to the load. Today, policies need to move from focussing exclusively on LCOE to considering the value of generated electricity as well.

Comparing the SV of different technologies – and not just their LCOE – provides a more complete picture and a sound basis for policy design (Figure). In the example below, Technology B has the lowest cost, but also a very low value – hence it would require the most support to trigger deployment. By comparison, Technology C has an intermediate cost but a very high SV. Its deployment would not require any support because an appropriate market design was already in place.

Figure 17-13 The link between VRE cost, SV and competitiveness



Key point • In well-designed markets, the relationship between cost and SV determines the need for financial support, or the degree of a technology' s competitiveness. If the capital cost of a technology – in other words, its LCOE – falls, the convergence between SV and LCOE can be used to plan the timing of investments, incentives, and infrastructure upgrades.

Figure shows the SV of different generation technologies in EDO modelling. This SV is consistent with the evolution and constraints of China's power system. In the stated policies scenario, the market value of wind and solar PV, along with their share increases, declines 10 % - 15 % relative to the coal-base unit. In the below-2-degree scenario, the value

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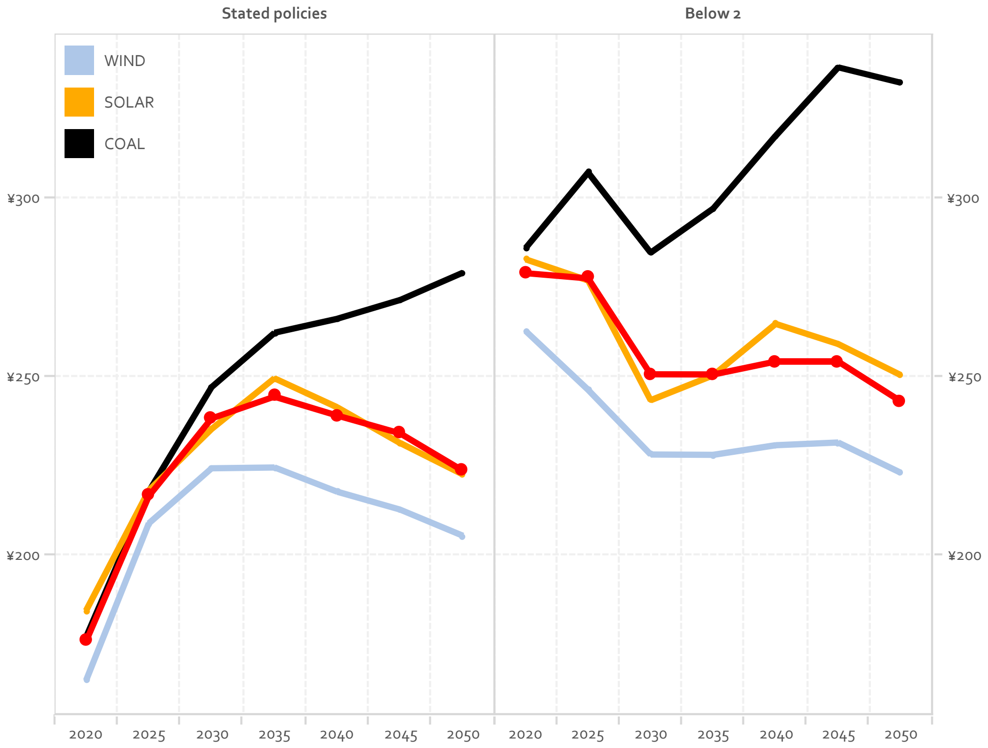
[111] An increase in flexible resources not only boosts SV for VRE; it increases the value of all inflexible technologies. Historically, the uptake of flexible resources such as pumped hydro storage or programmable electric heaters was used to integrate inflexible generation, especially from nuclear energy.

of variable resources remains higher despite their increased share; and the value of dispatchable generation increases despite making a lower contribution to the mix.

Figure 17-14 Average wholesale market value of renewables in EDO scenarios



Renewable policy support alternative to FiT

China adopted favoured Feed-in-Tariff (FiT) support for wind and solar PV generation after implementing its renewable energy law in 2005.In China's system, a FiT and a FiP (Feed-in-Premium) are practically the same. The coal power on-grid tariff that dominates the system has largely remained stable over the years, while the price for wind poweris a margin on top of the coal benchmark price. On a practical level, this structure was also reflected in the subsidy surcharge and in the subsidy issuance flow system.

Today, the subsidy system faces a serious problem of deficiency and imbalance in terms of revenue and expenditure, and policies are needed to reduce subsidy pressure. In this section, we discuss the pros and cons of policy support instruments other than FiT to finance the expansion of renewables.

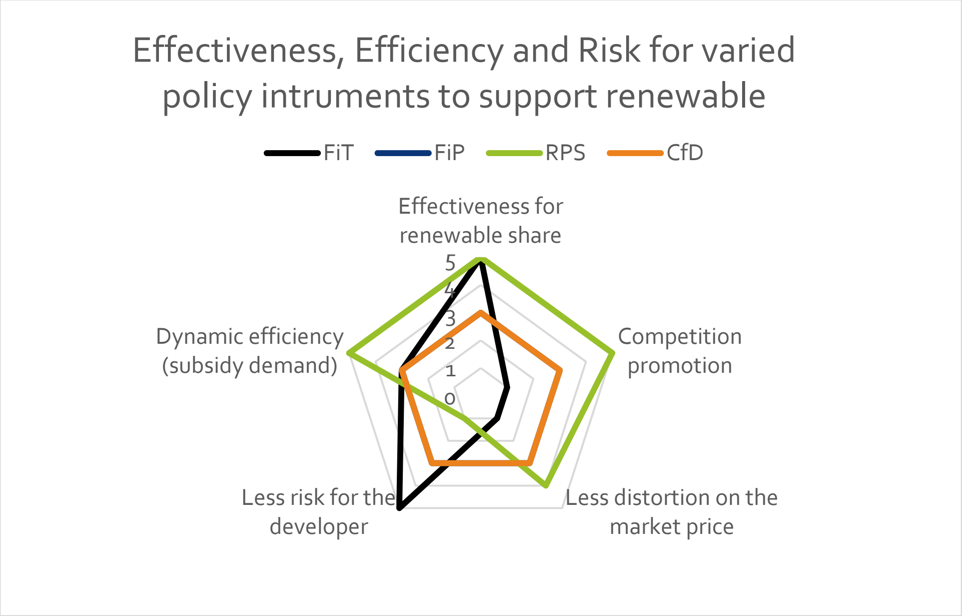
Renewable portfolio standards (RPSs) require that a share of electricity generation come from renewable technologies. Investment subsidies, production subsidies, FIT, FiP and CfD all provide an above-market price of electricity for renewable generators. Generally, these renewable electricity policies are costlier than an optimal emissions price because they do not incentivize low-cost opportunities to reduce emissions such as using natural gas instead of coal to generate electricity, leading to market price effect distortion. Figure provides an overview on the effectiveness, efficiency (cost-effectiveness), risk and flexibility of these various policy instruments compared to one another. The figure acknowledges that there are many second-level details, and that the devil is in those details.

A FiT is a direct payment for generation. The generators get the exact amount of money in the FiT per kWh of generation. A CfD emulates a FiT but isn't the same. A CfD is a financial contract (Zhao, 2012), which was mainly used in the UK as a hedging instrument for price volatility. The surcharge system paid the difference between the strike price and the market price. With CfD, low carbon generators receive a guaranteed and stable stream of revenues for their electricity production. That revenue consists of a market-determined price for electricity, plus a "top-up" payment determined by the difference between the fixed "strike price" stipulated in the contract and a market reference price for electricity.

If we assume that developers market their generation at the market price for every hour of every day, they would get the outcome of an equivalent FiT. If they market at different prices, however, their total remuneration would be different. A CfD, or CfD-FiT, is structured according to a market index. This can be more or less sophisticated. For instance, the index could be the average monthly price in a given market area. This system rewards (at least partly) projects that generate at the right time, which a FiT will not do. It also places part of the price fluctuation risk on the developer. (Risk is completely socialised with a FiT.) But, presumably, a CfD provides a subsidy element above the market price and a price hedge against general market price trends. A CfD can be regarded as a mechanism between a fixed FiT and a fixed FiP with a constant premium.

A new subsidy approach must have a detailed, value-explicit and an effective implementation. It must also include a spot market as the benchmark for most of the instruments.

Figure 17-15 Alternative renewable support policy instruments



Source:
https://www.gov.uk/government/collections/electricity-market-reform-contracts-for-difference;
NERA: Changes in hurdle rates for low carbon generation technologies, available at
http://www.nera.com/content/dam/nera/publications/archive2/20131209_NERA_Report_Assessment_of_Change_in_Hurdle_Rates.pdf
https://www.irena.org/DocumentDownloads/events/2012/November/Tariff/1_Rabia_Ferroukhi.pdf
Personal communication with Lars Bregnbaek and Kaare Sandholt, 27/06/2017.

Green certificates and corporate renewable energy purchasing are increasingly widespread in US and European countries as voluntary measures for procuring green energy. Corporate renewable Power Purchase Agreements (PPAs) allow corporations to buy renewable energy on a long-term basis directly from energy generators. In Europe, the volume of these agreements almost tripled in 2016 relative to 2015. In the US, corporate renewable PPAs accounted for almost half of the installed renewable energy capacity in 2016.[112] China's volunteer green certificate system was launched in July 2017. Details can be found in the following section.

Interaction of power market with green certificates, carbon market and other policies

Under textbook conditions, a well-designed energy-only market, combined with a mechanism to price negative environmental externalities (carbon market), should provide sufficient incentives to decarbonise the economy at least cost. While this is a compelling

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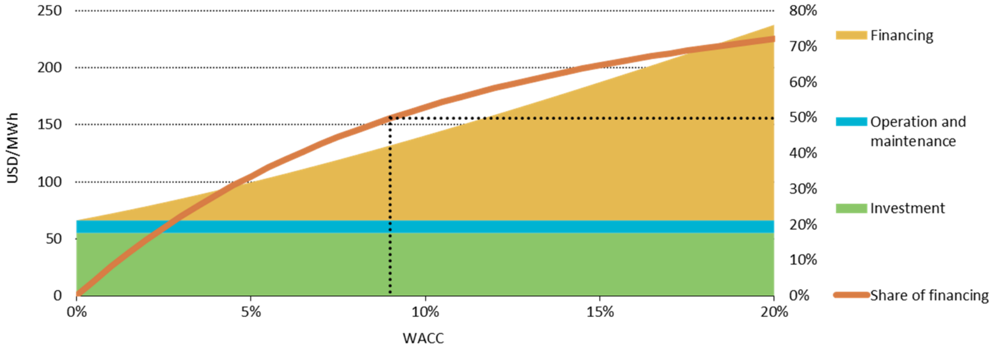
[112] See http://resource-event.eu/

vision in theory, it is not feasible, as there are many challenges associated with stimulating investments solely on this basis (IEA, 2016).

Attracting investments in low-carbon technologies means mobilising large amounts of funds for up-front investments. This is because the costs of low carbon technologies are mostly incurred during construction. The weighted average cost of capital (WACC) – a mix of the rate of return on capital and the interest rate for debt at which the necessary capital and debt can be obtained – is a crucial factor shaping the delivered cost of energy from low-carbon technologies. The lower the WACC, the less expensive low-carbon energy is. In turn, factors that increase the WACC drive up the cost of delivered electricity. In the case of solar PV, increasing the WACC from 4.5% to 9% drives up levelised costs considerably. If the WACC exceeds 9%, financing costs begin to dominate the overall cost of solar PV electricity (Figure , IEA, 2015).

Figure 17-16Impact of cost of capital on the levelised cost of solar PV



Key point: Financing costs can dominate all other components (equipment costs, O&M) of LCOE for solar PV.

This means that high risks (and thus high WACC) make investments in low carbon options more expensive, which in turn undermines their competitiveness. On liberalised wholesale markets – even with a high carbon price – low-carbon generators are exposed to significant risks.

Concurrent uncertainty about fossil fuel and carbon prices creates risks that deter low-carbon investment. In existing liberalised electricity markets, system operatorstend to call on generators with low short-run costs to meet demand. But it is often other technologies – with higher short-run costs – that set the margin price. For example, this is the case for CCS technologies that incur fuel costs. It can also be the case for fossil fuel power plants still present in the system (IEA, 2015).

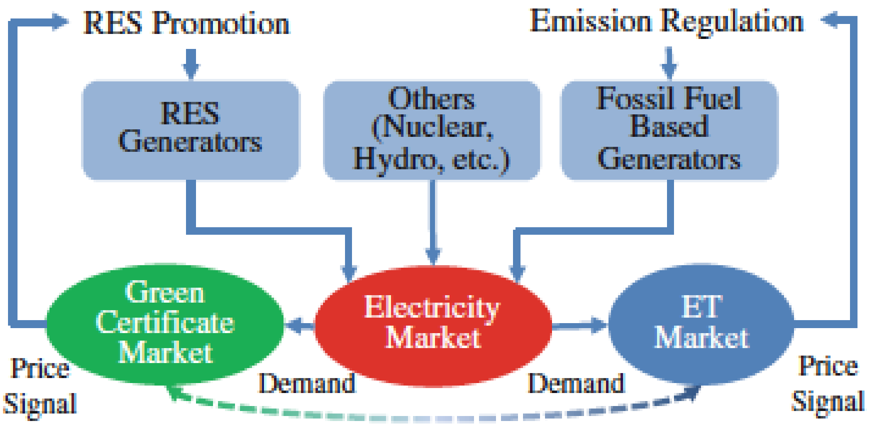
Fuel and emission costs determine the short-run costs of these price-setting technologies. When costs are high, low-carbon generators will benefit from high prices. But when prices decline, both high- and low-carbon generators will be exposed to low prices. The reason is that the benefits of low-carbon generation are saving fossil fuels (with the exception of CCS) and avoiding CO_2 emissions. As such, market revenues for low-carbon generation fall when the costs of fuel and emissions are low (IEA, 2015).

In turn, when demand can be met solely from supply with almost zero marginal cost, short-term prices can be expected to plunge to almost zero. This can create a large gap between the average long-run cost (i.e. the levelised cost of electricity or LCOE) on which investment decisions were made and the short-run cost that determines actual revenues. This gap represents an additional source of risk for low-carbon technologies. At very high shares of low-carbon generation, prices may be very low for extended periods of time.

As a result, mobilising investments in low-carbon sources such as renewables may require instruments to reduce risk and improve revenues certainty. One way to achieve this is to introduce a system of quota obligations and tradable certificates.

But the various mechanisms of pricing carbon and remunerating renewable energy producers and the general electricity market have complex interactions.

Figure 17-17 Interactions between various policy instruments in power and renewable domains



For example, paying generators money for green certificates on top of market prices can incentivise them to generate electricity, even when prices are negative – producers decide how to bid on the market based on the sum of the market and certificate prices – which can distort the operation of the power market. In principle, this can be fixed by, say, withholding electricity certificates for generation during times of negative prices, but this can be difficult to implement in practice. Similarly, trade across different regions can be distorted by uneven prices for carbon and renewable energy certificates, seeing how different systems have different footprints and limitations.

Given the practical challenges of mobilising investments, however, the aim should not be to avoid market distortions at all costs. Rather, a pragmatic approach is needed to reconcile different mechanisms in a way that leads to efficient outcomes that are in line with policy goals.

In China's case, the interaction of these factors – the carbon market, green certificates and power market reforms – must be carefully considered. Next year, we will devote a special focus to this topic moulded on The Power Market Pentagon, Agora's report on similar factors in Europe (2016).

17.5 Recommendations: Market design and policy essentials for enabling high levels of renewable integration

The greatly expanded deployment of renewable energy is imperative for socially sustainable and resilient economic and energy sector development in China. Yet realising the renewable adoption scenarios described in this report would not only benefit China, but also the rest of the world. To preserve the prospect of meeting the 2°C target set forth by the Paris Agreement, China's power sector needs to be fully decarbonised by the middle of this century, with the rest of the energy sector on track to achieving zero emissions(Kriegler et.al, 2013). Clearly, the magnitude of the challenge posed by climate change urges ambitious collective action at the global level. In China, severe environmental concerns, including poor air quality, augment the policy imperative to support green energy development, efficiency improvements and abatement measures.

The ratification of an improved market design in conjunction with other enabling polices will be essential for facilitating the expansion of non-hydro renewables to above 51% of total primary energy consumption and to73% of total electricity supply by 2050, as depicted in our Below 2°C scenario.

Considering current planning in China's cost-of-service power system, the following short- to medium-term changes to market design are essential:

- **Set a clear timeline for the phase-out and cancellation of the production quota for conventional power and inflexible cross-regional trading and interconnector use.** The modelling results showed that the production quotas and inflexible interconnector use would entailincremental cumulative system costs about 1 trillion Yuan RMB in 2016-2050, assuming the same renewable share target. The first change is already envisioned in an NDRC document published in 2017, with bilateral trading serving as the substitute for the planned quota.[113] This change can be complemented by explicitly adjusting the dispatch principle from *planned dispatch*[114] to *economic dispatch*, i.e. scheduling the power unit

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[113] It should be noted that the power system can't operate without a short-term mechanism to balance the residual load and manage stochastic factors including forecast error, variability output and outages. Hence, to achieve a reliable system, it's not enough to abolish the scheduling procedure.

[114] In this approach, the operating hours were allocated evenly across all generators of a given type through an annual planning process. From 2007 to 2010, energy-efficient dispatch was expanded to

based on its marginal costs. This could be an interim measure to improve economic efficiency before the market-based coordination between different balance areas is in place. Over time, the marginal cost of supply used to establish flows can be based on market prices. More market-based exchangeacross provincial boundaries is needed to better reflect the demand and supply dynamics at both the point of origin and destination of electricity flows.

- **Establish pilot trading systems that allow trading with short product duration and lead times (e.g. hourly products with day-ahead lead times), and strengthen capabilities for relevant hardware and software development.** The day-ahead market within one balancing area (i.e. region or province) could be a starting point for a short term market that better reflects variation in demand and intermittent renewable energy production, as well as start-up times for conventional generation. While establishing a national spot market by 2020 is unlikely, an interim target should be set for a coupled provincial or regional spot market that allows exchange between balancing areas, i.e. the coupling of smaller markets into a big one.
- **Promote the transparency and the regulation of system operation, dispatch and competition.** The availability of data on the generation and loads of various power producers is valuable for understanding key issues related to renewable integration, system adequacy and efficiency. Passing legislation to require the transparent and timely disclosure of hourly load and generation data – as has been done by US and European regulators – should be a priority task for Chinese policymakers in the near term.[115] The system operator has a key role in almost every exchange, and higher resolution data would enable improved system management and monitoring.

As regulators adjust policies to improve the function and efficiency of markets, stable expectations and a long-term commitment to renewable development are essential, especially if the FiT regime is altered.

- **Set a quantitative target for renewable expansion for the post-2030 era, and provide a clear policy signal for investors to support specific renewable technologies before full commercial viability is achieved.** This target should be based on China's domestic needs, and should align with the international effort to curb climate change. Varied policy instruments (e.g. green certificates, carbon trading) should be coordinated at the design stage to make sure their interaction would not hinder the cost-effective expansion of renewables or other climate mitigation efforts.
- **Improve the market value of renewables through technological development and additional policy measures.** To make renewables more competitive with conventional fuels, measures should be enacted to enhance the market value of renewables, as this would encourage higher renewable penetration rates. One route for improving market value is to encourage greater cost declines in renewable technologies. Other possible routes include a minimum carbon price or wind turbine generators with better output

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cover the several provinces within both of the State Grid and the Southern Grid regions. The extent to which energy-efficient dispatch has been fully implemented varies among these provinces, and it has not been extended nationwide as originally envisioned. .

[115] For example, https://transparency.entsoe.eu/ for the European part, and https://www.ferc.gov/docs-filing/dec-not.asp at the federal level.

profiles. Targeted measures can help renewables to become more economically attractive than conventional fuel sources, but patience is needed.

- **Post-FiT (feed-in tariff) policy instruments need to be carefully designed in order to maintain the economic feasibility of renewables while reducing distortions in the power market and ensuring long-term system adequacy.** Feed-in premiums (FiP), contracts for differences (CfD) and auctions of various types could be viable design options if short-term markets become better established. The current overcapacity situation in China might reduce concerns over long-term system adequacy, but renewables could be exposed to market risk if fossil fuel externalities are not internalised.

In the long run, an "energy-only" market is by no means sufficient for ensuring high renewable penetration rates and the deep decarbonisation of the power system. Policy measures should be enacted to improve the value of renewables in the long term while improving efficiency and reducing the distortions to the market.

The sequence of reform is important. The first steps taken should include ensuring the transparency of data on load and generator dispatch, and the adoption of rules and procedures that govern how the dispatch centre ensures system balance. Short-term spot markets will evolve once participants see how economic dispatch based on merit-orderis implemented. The yearly planned hours for power options could be phased out as changes in dispatch are phased in. Steps could then be taken in to simultaneously increase competition between both generators and retailers.

The renewables-based power system of the future would place less emphasis on baseload, and more emphasis on flexibility, decentralised generation, and integration. With intelligently sequenced policy and market changes, it should be possible for China to transition from a slow-moving and inflexible power system to one that is efficient, flexible, resilient and better able to integrate renewable generation. The new power system would rely less on subsidies, ensuring sufficient capital cost recovery for investment in renewables and conventional generation with high market and system value. The whole of society, including the electricity consumer, would enjoy clear benefits, including more affordable electricity rates.

18 Interconnector and Grid Development

18.1 Backbone Grid

Development of backbone grid

Seen from the history of grid construction in various countries, grid development is generally divided into three stages: the first stage is the formation of urban (regional) isolated grid; the second stage is the gradual formation of trans-regional and transnational large grid through interconnection; the third stage is the rapid development of intelligence simultaneously with expansion of grid interconnection to support green transformation of power system.

In North America, large scale hydro power development drove the great development of North America grid for the first time from the 1930s to the 1950s; with rapid increase in power demand and continuous rise of voltage level, interconnection of grid in North America was realized from the 1950s to the 1980s; currently, the grid in North America develops continuously based on the ideas of obtaining higher efficiency, mutually sharing resources and interacting intelligently, presenting the pattern of four synchronous grids with asynchronous interconnection.

In Europe, three large grids (France, Spain and Portugal Grid; Netherlands, Belgium, Germany, Austria and Czech Grid; Italy and Switzerland Grid) were formed in 1958, and thereafter Western Europe interconnected grid was gradually formed; in 1996, Western Europe grid was further synchronized with Central Europe grid; currently, Europe continuously develops eastward for interconnection with grids of countries in Eastern Europe and southward for interconnection with grids of countries along the Mediterranean coast, aiming to support the development of wind power, solar power and other green energy.

China is currently at the second stage of grid development, where the automation level is gradually improved, grid structure is continuously enhanced, interconnection is rapidly established and intelligent interaction develops steadily. The adaptive grid system for integrating the centralized and the decentralized renewable energy has been preliminarily established. However, the transmission efficiency requires further improvement.

(1) ontinuous enhancement of grid structure

China's power grid has witnessed more than 60 years' development. The highest voltage level is continuously improved and the distribution of the grids in all voltage levels is gradually perfected. The high voltage grids include 10kV, 35kV (66kV), 110kV and 220kV grids; extra-high voltage grids include 330kV, 500kV, DC ±500kV, DC ±660kV and 750kV grids; ultra-high voltage grids include AC 1,000kV and DC ±800kV grids.

In China, the length of transmission lines at 220kV and above reached 611,000km by the end of 2015, increased by 5.8% over the previous year. The total capacity of substation equipment at 220kV and above was 3.13 billion kVA, increased by 7.6% over the previous year.

Rapidly developed grid construction provides China with powerful grid support and continuously improved grids at all levels create favorable transmission conditions for renewable energy regardless of centralized access or decentralized integration.

(2) Rapid construction of interconnection

In China, generation resources and electricity demand are inversely distributed. The coal is mainly distributed in Northeast, North and Northwest China. The wind resources are mainly concentrated in North, Northwest and coastal regions of East China. The solar energy and photovoltaic resources are mainly distributed in Northwest. However, the load centers are mainly concentrated in southeast coastal regions and central regions. Therefore, with rapid development, trans-provincial, trans-regional and transnational grid construction has become an important measure in China for solving the problem of uneven resource distribution, optimizing generation resources and serving neighboring countries.

As at the end of 2015, North China grid was connected with Northeast grid through Gaoling back-to-back DC project and with Northwest grid through East Ningxia - Shandong ±660 DC project. Meanwhile, Fugu and Jinjie power plants in Shaanxi were connected with South Hebei grid through 500kV AC line via point-to-network scheme, delivering power to North China grid, and connected with Central China grid through East Shanxi - Jingmen 1,000kV Ultra-high voltage AC project, benefiting from mutual support between hydropower in South and thermal power in North. West Inner Mongolia grid delivered power to Mongolia through 220kV and 110kV transmission lines.

East China grid is the most important receiving-end system in China, which was connected with Central China grid through Gezhouba - Nanqiao DC, Longquan - Zhengping DC, Yichang - Huaxin DC, Xiangjiaba - Shanghai DC, Three Gorges - Shanghai two-circuit DC (Tuanlin - Fengjing DC) and Jinping - South Jiangsu DC lines, for receiving large scale hydro power from Three Gorges, Gezhouba and Sichuan. Yangcheng power plant in Shanxi was connected with Jiangsu grid through 500kV AC line via point-to-network scheme, delivering power to East China grid.

Central China grid, located at the center of national grids, was connected with North China grid through Southeast Shanxi - Jingmen 1,000kV Ultra-high voltage AC project, and connected with Northwest grid through Lingbao back-to-back project and Deyang - Baoji DC project, for receiving power from North China and northwest coal power bases and benefiting from mutual support between hydro power and thermal power.

In 2013, one pole of the bipolar DC system from South Kumul to Zhengzhou was commissioned, which further enhanced the transmission capability from northwest to Central China. Central China grid was connected with East China grid through Xiangjiaba - Shanghai DC, Jinping - South Jiangsu DC, Gezhouba - Nanqiao DC and Longquan - Zhengping DC lines, for transmitting hydro power from Three Gorges, Gezhouba and Sichuan to East China load center. It was connected with South grid through Jiangling - Echeng (Three Gorges - Guangdong) DC project, transmitting hydro power of Three Gorges to Guangdong load center. Liyujiang hydro power plant in Hunan was connected with Guangdong grid via point-to-network scheme for delivering power to Guangdong grid.

Northeast grid was connected with North China grid through Gaoling back-to-back DC project and connected with Russian grid through Heihe back-to-back DC project that was officially in commercial operation in 2012, delivering power to North Korea. In Northwest region, abundant thermal power and renewable energy including wind and solar power were delivered to Central China grid through Lingbao back-to-back project, Deyang - Baoji DC project and South Kumul - Zhengzhou DC Project. It was connected with North China grid through East Ningxia - Shandong DC project, delivering power from East Ningxia coal power base and wind power base to Shandong load center, and connected with Central Tibet grid through Golmud - Lhasa DC project, which greatly alleviates the problem of long term power shortage in Tibet Grid.

South grid was connected with Central China grid through Jiangling - Echeng DC project, receiving hydro power from Three Gorges, and connected with Hong Kong and Macao grids through AC transmission lines, delivering power to Hong Kong and Macao. It interconnects to Southeast Asian countries including Vietnam, Myanmar and Laos through 220kV and 110kV AC lines, realizing mutual power supply in the regions of borders. Liyujiang power plant in Hunan was connected with Guangdong Grid through 500kV AC line via point-to-network scheme, delivering power to South Grid. In South grid, a multi-circuit AC-DC hybrid trans-provincial corridor was constructed for transmitting electricity from the west to the east, delivering abundant hydro power in Yunnan and Guizhou to the load centers in Guangdong and Guangxi.

(3) Efficiency improvement of grid resource allocation

Compared with Europe and the US, the utilization of transmission lines in China is relatively poor. In October 2012, National Energy Administration (former State Power Supervision Commission) issued the *Research Report on Grid Operation during "the 11th Five-Year Plan" period*, stating that "the utilization of 220kV and above transmission lines in China is much poorer than that of many foreign countries, with serious waste". Grids in China are similar to these in Europe and the US. The poorer line utilization in China results from the impact from the planning and scheduling based dispatch mechanism.

In terms of supporting installed capacity in 2015, the proportion of installed capacity to the circuit length of transmission lines in China was about 2,583kW/km, being 72.7% of grids in Europe (2015) and 67.9% of grids in the US (2012) and lower than that of grids in Japan and South Korea. Referring to the utilization level of grids in the US, current grids in China could support additional 720GW installed capacity. In terms of power transmission in 2015, the proportion of the total electricity consumption to the circuit length of transmission lines in China was 9.64GWh/km, being less than 80% of that in the US and much lower than that of Japan and South Korea (respectively 22.91GWh/km and 15.22GWh/km). Referring to the transmission level of US, current transmission network in China could support the power consumption of 740GWh, which means that no more new transmission line would be needed during "the 13th Five-Year Plan" period in China, as shown in Table 1. In terms of regions, most western regions were developing in the form of "large energy base + exportation" due to inverse distribution of generation resources and consumptions in China. Therefore, the ratio of the installed capacity of transmission network to the length of the transmission lines in China's western regions was higher than that in eastern and central regions. However, the ratio of electricity consumption to the length of the transmission lines was lower than that in eastern and central regions, as shown in Figure 1. In addition, the ratio of trans-provincial power exchange to the length of the transmission lines in China was also lower than that of grids in Europe. Therefore, the capability of trans-provincial and trans-regional resource allocation requires further improvement, which, to some degree, limits utilization of more renewable energy resources including wind and solar power

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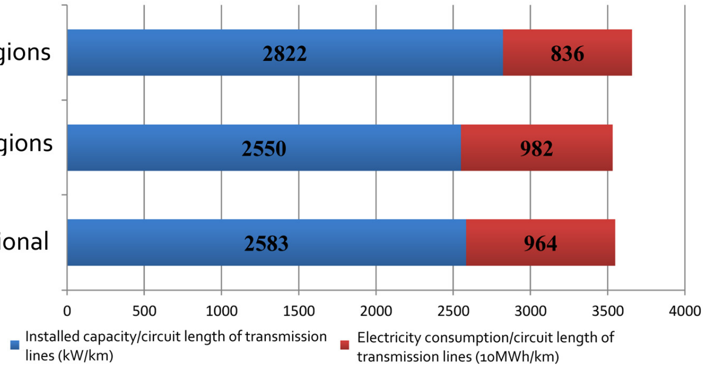
Table 18-1 Comparison of Transmission Network Efficiency

Transmission network	Installed capacity	Electricity consumption	Circuit length of transmission line	Trans-provincial and transnational exchanged power energy	Installed capacity/line	Power energy/line	Exchanged power energy/line
	10MW	**GWh**	**km**	**GWh**	**kW/km**	**10MWh/km**	**10MWh/km**
China (2015)	152527	5693300	590435	948209	2583	964	161
Europe (2015)	99145	3270541	278936	488208	3554	1173	175
US (2012)	116800	3831000	307000	——	3805	1248	——
Japan (2014)	31530	964868	42113	——	7487	2291	——
South Korea (2014)	9983	499046	32795	——	3044	1522	——

Figure 18-1 Comparison of Transmission Network Efficiency in Different Regions in China



Prospect of backbone grid development

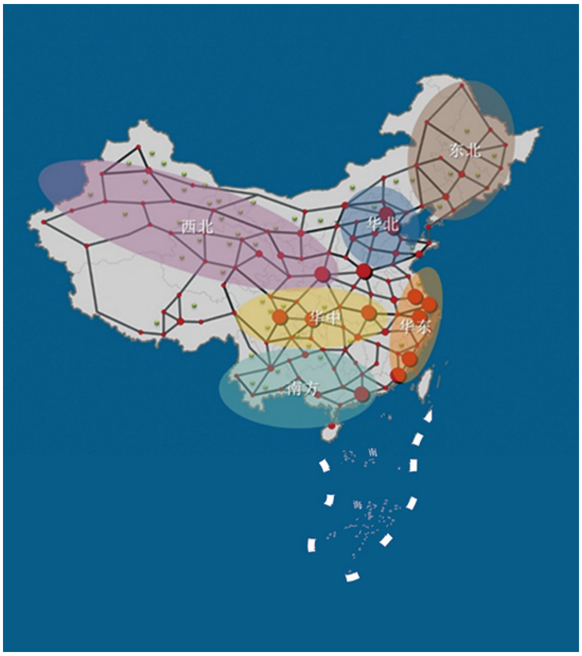
For China's backbone grid development, the following principles should be adopted: adaptive friendliness, economic friendliness and green friendliness. The grid construction is aligned to the developments of power generation and demand, gradually realizing the coordinated planning of the grid construction according to the power generation development and demand growth, strengthening the overall planning of provincial and regional grids to reduce redundant grid construction.

On top of continuous improvement on the existing provincial and regional backbone grids, the coordination between the grids with different voltage levels is to be enhanced, benefiting from the flexible interconnection between large grids, strengthening the mutual support capability between regions and provinces, increasing the efficiency of the resource allocation via grids.

The appropriate deployment of the energy exportation from regions with abundant energy is to strictly control the cost of grid construction, constructing a "west-east transmission" corridor in combination of ultra-high voltage and conventional transmission systems, optimizing power dispatch. Aimed at developing an energy saving, environmental friendly and low carbon system, a scientific and feasible power scheduling principle and detailed measures are formulated for strengthening the integration capability of the renewable energy.

The power system intelligence is to be comprehensively improved, strengthening capabilities of integrating and optimally allocating various energy sources, to realize the diversified interactions between consumers' supply and demand and comprehensive allocation of energy production and consumption, maximizing the functions of the grids in the modern energy system.

Figure 18-2 Schematic Diagram of Friendly Backbone Grid in China



18.2 Distribution Network

Distribution network development

The distribution network consists of overhead lines, cables, towers, distribution transformers, disconnectors, reactive compensators and some ancillary facilities, supplying and distributing power to users. As the requirement for power supply safety and reliability has been continuously enhanced, urban construction scale and economic development call for high requirements for the distribution network, i.e. relatively perfect multi-loop feeders, good urban planning and electricity path distribution, reliable primary and secondary and network communication equipment.

The distribution network structure determines the reliability and the flexibility of network operation. Various countries have various designs. Taking urban distribution network as an example, the cable network in urban area of Paris is in three-loop network T-connection or double-loop T-connection mode. The cable network in London is in multi-branch and multi-connection mode. In Tokyo, 22kV cable network is built with main lines and backup lines in loop within mesh network, and 6kV overhead network is in multi-section and multi-connection mode, and the cable network is in multi-segmentation and multi-connection mode. The cable network in Singapore is in “petal mode”, i.e. looped network in normal closed connection. Despite differences in specific topologies, the advanced grid structure at home and abroad basically tends to be developed in “dumbbell shape”, with the core principle of “intensifying the two ends and simplifying the middle”, which can guarantee the safety and reliability while avoiding repeated construction.

The distribution network in China is classified as high voltage, medium voltage and low voltage according to voltage levels, where high voltage distribution network is often 35-110kV, medium voltage distribution network generally covers 6-10kV and low voltage distribution network is 220/380V. In megapolis with higher load, the 220kV grid can also have distribution function. It can be classified as urban, rural and factory distribution networks according to the functions of power supply areas. Considering the required level of the power supply security, it is appropriate to have simple and clear structure of the distribution networks, with different grid structures for different power supply areas. In China, the typical cable grid structures mainly include double-loop network and single-loop network, as respectively shown in figures below:

Figure 18-3 Schematic Diagram of 10kV Double-loop Network (Cable)

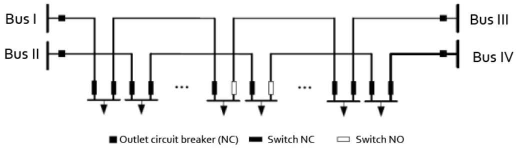
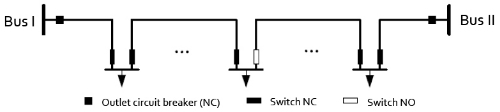


Figure 18-4 Schematic Diagram of 10kV Single-loop Network (Cable)



The typical grid structures of overhead lines include overhead multi-segmentation and single connection, and overhead multi-segmentation and moderate connection, as respectively shown in figures below:

Figure 18-5 Schematic Diagram of 10kV Multi-segmentation and Single Connection Structure

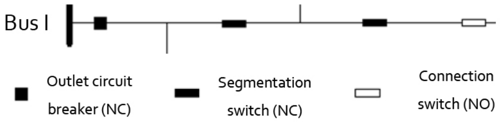
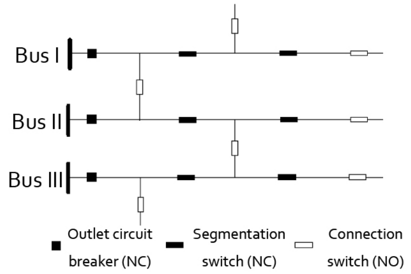


Figure 18-6 Schematic Diagram of 10kV Multi-segmentation and Moderate Connection Structure



(1) Continuously improved automation level

In China, investments in distribution networks have been continuously increased. The substation capacity and line length of the distribution network have been doubled. The grid structure tends to be rationalized and the power supply capability has been greatly strengthened, which have significant effects on the rapid growth of the urban and rural economic and social development.

Advanced relay protection devices, substation integrated automation system, grid scheduling automation system and grid security and stability control system have been applied extensively. Relay protection developed relatively late but rapidly. Currently, microprocessor protection devices have comprehensively replaced traditional protective devices and are closely combined with informatization, automation and intelligence, which significantly improves the stability of the power system operation. Digital substation automation system has been constructed rapidly in China, which effectively improves measurement accuracy and avoids problems including electromagnetic compatibility, transmission overvoltage and two-point grounding. The functions of substations can share a unified information platform, which further improves automatic operation and management. In addition, the power scheduling automation in China has experienced the technological development process, from introduced application system to domestic application system, from special machine to universal machine, and from no OS to special OS, and finally to open OS. The construction of technical supporting system for intelligent grid scheduling has been currently completed. With improvement of grid automation level, the accidents of safety and stability in mainland grids have been reduced greatly. Automatic power scheduling and substation management help integrate renewable energy into power system in a flexible way, and deliver to power clients accessibly. The advanced relay protection devices provide important safety guarantee for integrating renewable energy and operating the system.

(2) Steady development of intelligent interaction

The intelligent micro grid construction in China is promoted steadily in order to adapt to rapid development of the distributed generation. It is mainly based on the local intelligent energy comprehensive utilization system built by local distribution grids with mutual compensation among various energy resources including wind, photovoltaic and natural gas, and power-grid-load coordinated interaction. With high penetration level of renewable energy, it can almost achieve the balance between local energy production and consumption through storage devices and optimal energy allocation, and can realize flexible interaction with, or relatively independent operation of, public grids as needed.

However, the intelligent microgrid in China is still at the initial stage. Some pilot projects for demonstration of microgrid projects can be roughly classified in three categories: microgrid in remote regions, island microgrid and urban microgrid.

1) Microgrid in remote regions: in China, the population density is low and ecological environment is vulnerable in remote regions, so that expansion of the conventional grid is costly and fossil fuels based power generation is harmful to environment. However, renewable energy sources including wind and solar power in remote regions are abundant. Therefore, using local distributed renewable energy in independent microgrid is an appropriate solution for supplying power to the remote regions. In China, a batch of microgrid projects have been currently constructed in remote regions in Tibet, Qinghai, Xinjiang and Inner Mongolia, for the power supply in these regions.

2) Island microgrid: in China, the diesel based power generation with limited timeis applied in islands. There are still about one million households of coastal or island residents living with lack of electricity. Considering the high cost and the difficulties in transporting diesel to islands, construction of island microgrid using distributed abundant renewable energy on islands is a preferred solution for the power supply. In China, a batch of island microgrid demonstration projects have been constructed to carry out theoretical, technical and application researches in practice.

3) Urban microgrid and other microgrids: in addition to microgrid in remote regions and island microgrids, China has also constructed urban microgrid demonstration projects. The key objectives of the demonstrations are to integrate distributed renewable energy, provide high quality and various reliable power supply services, and achieve comprehensive utilization of cooling and heating power. In addition, there are some microgrid demonstration projects with special functions, such as the Sea Water Desalination Microgrid Project in Dafeng, Jiangsu. China has provided a flexible and comprehensive utilization path for integrating more distributed renewable energy through continuously increased investments in grid intelligence and multi-type energy complementation like wind and solar power complementation, and hydro and solar power complementation. The intelligent construction also becomes an important goal of grid development at all levels in China.

Table 18-2 Microgrid Demonstration Projects in Remote Regions

Name/location	System composition	Main characteristics
Shiquan River Microgrid in Ngari Prefecture of Tibet	10MW photovoltaic power station, 6.4MW hydro power station, 10MW diesel generation unit and energy storage system	Multi-energy complementation between photovoltaic power, hydro power and thermal power; high altitude and awful weather
Jijiao Village Microgrid in Shigatse Prefecture of Tibet	Total installed capacity of 1.4MW, consisting of hydro power, photovoltaic power generation, wind power, battery energy storage and emergency diesel generation	Wind and solar power complementation; high altitude and difficult natural conditions
Rting Rngul Bon Dgon Microgrid in Nagqu Prefecture of Tibet	15kW wind power, 6kW photovoltaic power generation and energy storage system	Wind and solar power complementation; the first village microgrid in Tibet
10MW Hydro and Photovoltaic Power Complementation Microgrid in Batang Town, Yushu County, Yushu Prefecture, Qinghai	2MW single axis tracking photovoltaic power generation, 12.8MW hydro power and 15.2MW energy storage system	MW-level hydro and photovoltaic power complementation, one of largest photovoltaic microgrid power stations in China
Large Scale Photovoltaic Energy Storage Microgrid in Zadoi County, Yushu Prefecture, Qinghai	3MW photovoltaic power generation and 3MW/12MWh two-way energy storage system	Parallel connection of multiple energy storage converters, and photovoltaic power and storage complementation and coordination control
Intelligent Photovoltaic Power and Storage Street Lamp Microgrid in Menyuan County, Haibei Prefecture, Qinghai	Centralized photovoltaic power generation and lithium battery energy storage	First similar system in plateau farming regions, changing the current situation where the lifetime of outdoor lead acid batteries is two years
New Energy Microgrid Demonstration Area in New Town of Turpan, Xinjiang	13.4MW photovoltaic capacity (including photovoltaic and solar power) and energy storage system	Solar energy utilization and building integration project with the largest scale and most comprehensive technology application currently in China
Microgrid of Taiping Forest Farm in Eerguna, Inner Mongolia	200kW photovoltaic power generation, 20kW wind power, 80kW diesel generation and 100kWh lead acid battery	Renewable energy power supply solution in forest farm in remote region
Old Barag Banner Microgrid in Hulunbuir, Inner Mongolia	100kW photovoltaic power generation, 75kW wind power and 25kW×2h energy storage system	Newly built migrant village and grid-connected microgrid

Table 18-3 Island Microgrid Demonstration Projects

Name/location	System composition	Main characteristics
Dong'ao Island MW-level Intelligent Microgrid in Zhuhai, Guangdong	1MW photovoltaic power generation, 50kW wind power generation and 2MWh lead acid battery	Forming intelligent microgrid with diesel generator and transmission and distribution system, increasing the rate of renewable energy on the whole island to be over 70%
Dan'gan Island Microgrid in Zhuhai, Guangdong	5kW photovoltaic power generation, 90kW wind power generation, 100kW diesel generation, 10kW wave power generation and 442kWh energy storage system	Having the first independent renewable energy power station in China; capable of utilizing wave energy; with capacity of seal water desalination at 60t/day
East Fushan Island Microgrid in Zhejiang	100kW photovoltaic power generation, 210kW wind power generation, 200kW diesel generation and 1MWh lead acid battery energy storage system	An island with residents at the most east end of China; with capacity of seal water desalination at 50t/day
Nanji Island Microgrid in Zhejiang	545kW photovoltaic power generation, 1MW wind power generation, 1MW diesel generation, 30kW ocean energy generation and 1MWh lead acid battery energy storage system	Capable of utilizing ocean energy; introducing electric vehicle charging and changing station, intelligent electric energy meter, user interaction and other related advanced technologies
Luxi Island Microgrid in Zhejiang	300kW photovoltaic power generation, 1.56MW wind power generation, 1.2MW diesel generation, 4MWh lead acid battery energy storage system and 500kW×15s super-capacitor energy storage	With function of flexible switching between microgrid connection and off-grid mode
Yongxing Island Microgrid in Sansha, Hainan	500kW photovoltaic power generation and 1MWh lithium iron phosphate battery energy storage system	The southernmost microgrid in China

Table 18-4 Urban Microgrid Demonstration Projects

Name/location	System composition	Main characteristics
Integrated Microgrid at 2# Energy Station in Sino-Singapore Tianjin Eco-City	400kW photovoltaic power generation, 1,489kW gas generation, 300kWh energy storage system, 2,340kW ground source heat pump unit and 1,636kW electric refrigeration unit	Flexible operation modes; coordinating comprehensive utilization of power, cooling and heating
Microgrid at Public House Exhibition Center in Sino-Singapore Tianjin Eco-City	300kW photovoltaic power generation, 648kWh lithium ion battery energy storage system and 2×50kW×60s super-capacitor energy storage system	"Zero energy consumption" building, overall balance in generating capacity and electricity consumption in the whole year
Nanjing Power Supply Company Microgrid in Jiangsu	50kW photovoltaic power generation, 15kW wind power generation and 50kW lead acid battery energy storage system	Energy storage system is capable of smoothening fluctuation of wind and solar power output; enabling seamless switching of grid-connection/off-grid modes
Narada Power Source Co., Ltd. Microgrid in Zhejiang	55kW photovoltaic power generation, 1.92MWh lead acid battery/lithium battery energy storage system and 100kW×60s super-capacitor energy storage	Battery energy storage is mainly used for "peak load shifting"; applying container type, with function modularization, realizing plug and play
Ecological Village Microgrid in Chengde, Hebei and Microgrid in Foshan, Guangdong	50kW photovoltaic power generation, 60kW wind power generation, 128kWh lithium battery energy storage system and three 300kW gas turbines	Providing power supply guarantee for peasant households in the region, realizing double-power supply, and improving utilization voltage quality and combined cooling, heating and power technology
Intelligent Microgrid in Yanqing District, Beijing	1.8MW photovoltaic power generation, 60kW wind power generation and 3.7MWh energy storage system	Combining distribution network structure design in China, with multi-stage microgrid framework and level-to-level management, smoothly realizing grid-connection/off-grid switching
Photovoltaic power and Heat Storage Integration Microgrid of State Grid Hebei Electric Power Research Institute	190kW photovoltaic power generation, 250kWh lithium iron phosphate battery energy storage system, 100kWh super-capacitor energy storage, electric vehicle charging pile and ground source heat pump	Connected with ground source heat pump to solve the problem of start-up impact; AC-DC hybrid microgrid
Wind Power Sea Water Desalination Microgrid in Dafeng, Jiangsu	2.5MW wind power generation, 1.2MW diesel generation, 1.8MWh lead carbon battery energy storage system and 1.8MW sea water desalination load	Researching & developing and applying the first large scale island operation control system with wind power directly offering load in the world

The development of microgrid in China still faces weak situations from government planning, standard-setting, research and development of related equipment, etc., detailed as follows: 1) The technologies of microgrid are not mature yet. At present, the construction of the pilot projects is mainly used for the research and verification of key technologies of microgrid; from the results of actual application, most of the pilot projects are still very immaturein such key technologies as exchange power control, seamless switching of grid connection and separation, and energy optimization management. 2) China lacks a unified definition and standards of microgrid. The definition, design specification, reliability, energy storage and other requirements of microgrid have not yet been issued in China. 3) China lacks a mature commercial operation mode of microgrid. t present, the development of microgrid at home and abroad is in the early stage and no relatively mature commercial operation mode has been discovered. China's microgrid demonstration projectsare also based on the purpose of experimental demonstration and the lack of a mature operation mode has become an important factor restricting the development of microgrid. 4) The setting of policy system is not conducive to the development of microgrid.The microgrid is relatively poor in economy, mainly because the power generation cost is relatively high; the economy of microgrid can only be fully embodied by introducing special policies on electricity and fuel prices. However, China lacks incentive policies for microgrid, and it is also short of the standards and systems for assessing the energy efficiency and power supply reliability and providing voltage support services of microgird.

(3) Requirement for improving power supply reliability of distribution network

At the end of last century, China took power source construction as the key point of power system development due to impacts of serious power shortage, which results in continuously exposed problems including old and outdated distribution network equipment and insufficient power supply capacity, poor reliability of supply and low electricity quality in many provinces and cities.

The distribution network development in China experienced the insufficient investment at the end of the 20th century, enhanced passive investment at the beginning of the 21st century and then enhanced active investment starting from the 12th Five-Year Plan. The distribution network construction has become one of the key points in the current grid development in China. However, the distribution network construction is still relatively backward in China compared with foreign developed countries.

In China, the reliability of the distribution network was poor before 1992, and then rapidly developed with a "spiral escalation". Currently, the urban distribution network in China is gradually approaching the high reliability level, while the rural distribution network development is still relatively backward. In 2015, the overall power supply reliability in China reached 99.8801% with average interruption time of 10.5h/household, where urban power supply reliability reached 99.9534% with average interruption time of 4.05h/household, and rural power supply reliability was about 99.8545%, with average interruption time of 12.74h/household. In terms of regions, the power supply reliability of East China grid was the highest, reaching 99.9068% with average interruption time of 8.16h/household, followed by North China grid and South grid and closely followed by Central China grid and Northeast grid. The power supply reliability of Northwest grid was poor, being about 99.7967% with average interruption time up to 17.81h/household, see Table 5.

Internationally, the power supply reliability index in the US was relatively stable, the annual average interruption time was 2.23h/household without considering major event days, and the total interruption time was estimated as 3.8-5h/household with above considerations. The power supply reliability in Japan since 1986 remained above 99.99%, with average interruption time basically below 0.876h/household.

Compared to the US and Japan, it can be found that although the distribution network construction in China has been promoted steadily and the power supply reliability for users has been greatly increased, the power supply reliability is still at initial stage with large space for improvement. In particular, with the increase in the penetration level of the renewable energy including wind and photovoltaic power, the requirement for the reliability level of power supply will be raised, which calls for further enhancing the construction of the distribution networks in China.

Table 18-5 Grid Power Supply Reliability in Regions

	Power supply reliability (%)			Average interruption time (h/household)		
	Overall	**Urban**	**Rural**	**Overall**	**Urban**	**Rural**
National	99.8801	99.9534	99.8545	10.5	4.08	12.74
North China	99.8930	99.9568	99.8712	9.38	3.79	11.28
East China	99.9068	99.9659	99.8860	8.16	2.99	9.98
Central China	99.8823	99.9564	99.8538	10.31	3.82	12.81
Northeast	99.8512	99.9533	99.8090	13.03	4.09	19.73
Northwest	99.7967	99.9210	99.7581	17.81	6.92	21.19
South	99.8931	99.9628	99.8731	9.37	3.26	11.12

(3) Insufficient adaptability of high penetration of distributed power source

In China, the 10kV grid structure is still weak. Many 10kV lines are still not inter-connected. There is a significant difference between urban and rural distribution networks. The interconnection of rural distribution network is only 1/3 of that of urban network. Though automation has been developed significantly in construction of urban distribution networks, the time for fault diagnosis, isolation and recovery is still long. The network reconstruction and self-healing cannot be realized and the mutual supply capability among distribution networks is poor.

In addition, the informatization management of distribution network is relatively lagged. The basic data involved in the distribution network management is scattered in different systems. The data standard and the model among systems are not consistent, lacking of common data maintenance and sharing mechanism. Due to limited distribution network investment, the network communication and information system development is relatively lagged, which results in low refined management degree of distribution network, even certain dead zone of management.

What's worse, traditional distribution network planning and design method cannot take or rarely takes into account the effects from distributed power sources and adjustable loads. The distribution network capacity is designed based on the maximum demand, without considering control effects, such as active power regulation during operation. This practice is relatively economical and effective for past passive distribution networks. However, with rapid increase of distributed renewable energy in recent years, it's hard to fully utilize distributed resources to achieve the optimal technical and economic effect with respect to active distribution networks. Additionally, traditional distribution network lacks technological means for active regulation and control, which makes distributed power sources hardly participate in system voltage and reactive control, and thus hardly provide auxiliary services. The adjustability of load in distribution networks is poor. The power consumptions and utilization time are adjustable for electric vehicles, electric heaters, washing machines and lighting equipment in distribution networks. They are important power balance resources in system. In the conventional distribution networks, the regulation capability of the adjustable load is rarely taken into account in the planning, and there is lack of technological means. Thus, the load absorbs power from the grid according to its need, which leads to waste the resource – "adjustable load".

(4) Rapid development of active distribution network, internet of energy and other technologies

The traditional distribution network faces many challenges with the increasing access capacity of distributed power supply, the rapid popularization of electric vehicles and the increase of controllable load. For coping with these new situations, the traditional distribution network has been gradually changed from passive mode to active mode, namely from passive network to active network, realizing the automation of distribution network. Relying on the support from the National "863 Program" and other major projects, the construction of demonstration projects of active distribution network is commenced in

Guangdong, Beijing, Fujian, Guizhou and other places in China; the key technologies of active distribution network and the optimization technology to promote renewable energy consumption have been developed rapidly; the planning and design method, operation management mode, source network load coordination and control technology, and other multidimensional innovation of active distribution network have greatly promoted the flexible local consumption of renewable energy and made the active distribution network to provide users with reliable, high-quality, efficient and diversified power services in a better manner. In addition, the rapid development of the internet of energy, the future power distribution system shall be oriented to the evolution of the internet of energy; the distribution network needs to promote the coordinated operation of "source-grid-load - storage", integrate the coordinated multi-energy complementation of electricity, heat, gas, transportation, etc., promote the combination of distribution network and big data information system, and advance energy production and consumption "Internet +" business mode; however, the combination of distribution network and internet of energy is still in the stage of theoretical research, demonstration and trial, which needs further industrialized development.

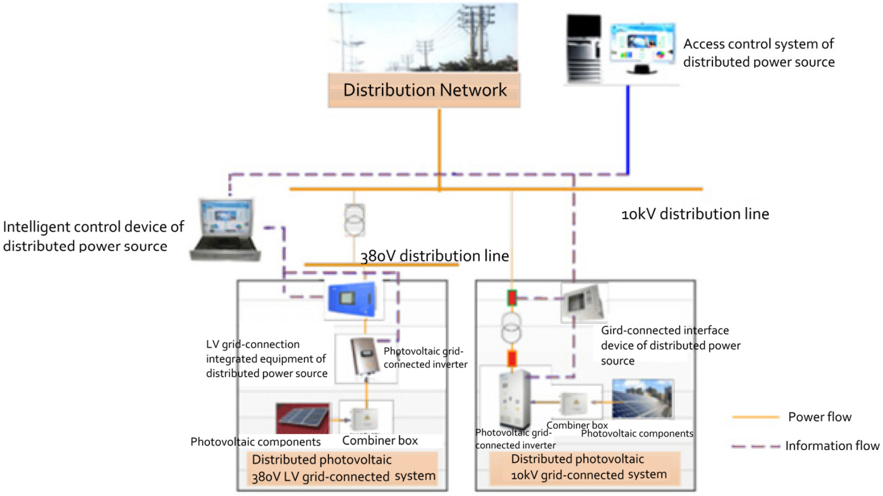
Prospect of distribution network development

For more rapid development of distribution networks in China, it's necessary to accelerate construction of modern distribution networks with urban and rural overall development, safety and reliability, economy and efficiency, advanced technologies, environmental friendliness and matching with moderately prosperous society, intensify unified planning of distribution networks, and perfect the standard system.

In central cities (regions), the advanced distribution network is to be constructed, focusing on development and reliability. In urban areas, appropriate look-ahead distribution network construction can be carried out with consideration of the needed development of the national new urbanization process to actively meet the requirements for diversified access to renewable energy, distributed power sources and electric vehicle charging infrastructure.

The "Internet +" intelligent energy will be comprehensively constructed to promote deep integration of distributed energy with Internet technology, active distribution network technology and energy storage technology, to realize deep integration among intelligent infrastructure of energy production and consumption, multi-type energy coordination, comprehensive energy network construction and infrastructure of energy and communication. The flexible trading mechanism will be established for green energy, forming the energy supply pattern with comprehensive coordination of various distributed energy sources, green and low carbon, and intelligent interactions.

Figure 18-7 Schematic Diagram of Intelligent Distribution Network



18.3 High Voltage Direct Current (HVDC)

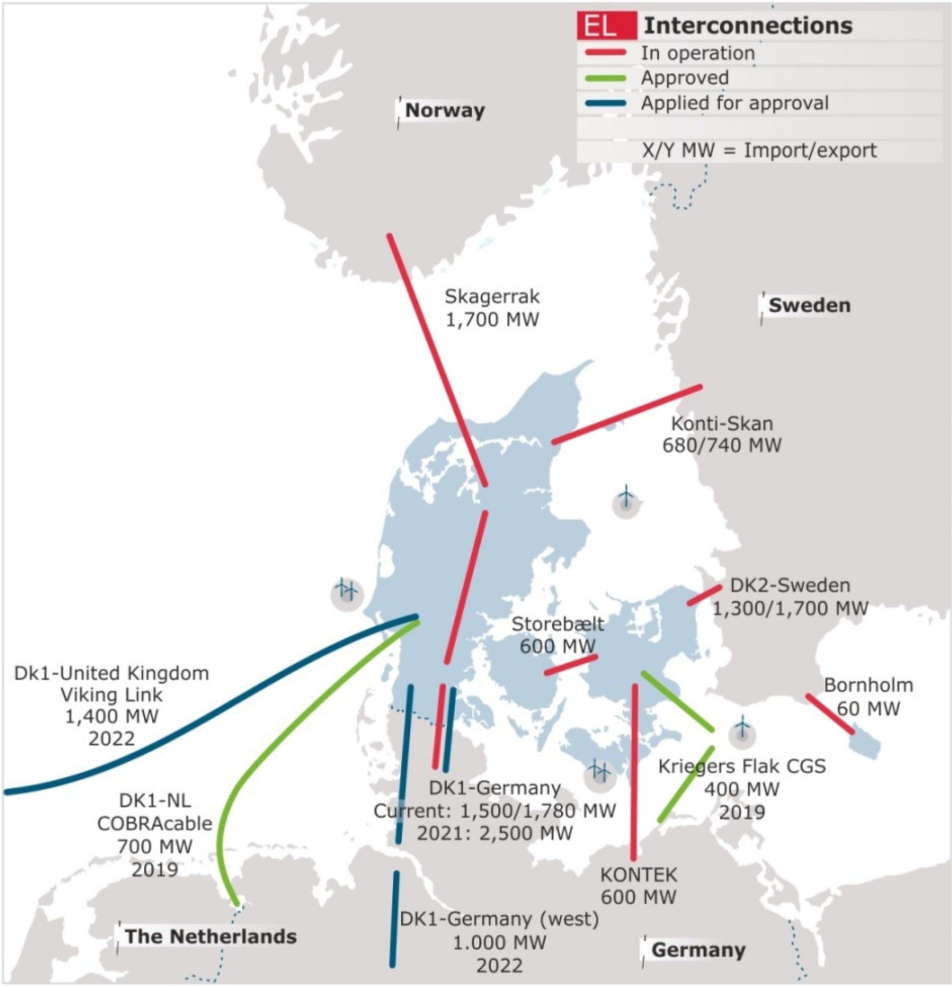
High Voltage Direct Current (HVDC) is connected with the AC system at sending end and receiving end through converter stations. It realizes efficient power transmission through rectification and inversion process. HVDC has lower energy losses than the traditional AC transmission. Moreover, it requires fewer transmission lines, smaller areas of transmission corridor and no reactive compensations for the lines. However, as the AC-DC conversion relies on converters, HVDC is more economical than AC transmission only for long-distance and cross-sea transmissions. It is also the only measure for connecting the asynchronous grids. As rapid development of power electronic technologies, HVDC has been becoming more and more popular in domestic and foreign transmission systems.

Danish experience

The functionality of the Danish HVDC links are well designed for maintaining the high transmission security, ensuring the well-functioning of the electricity markets and handling the emergent situations caused by the unexpected fault occurrences.

The first interconnection between Sweden and the western Danish transmission system was established in 1965 with the 250 MW 250 kV Konti-Skan HVDC link (see Figure). The converter stations were based on mercury-arc valve technology. A second Konti-Skan HVDC link rated 360 MW was added to Konti-Skan (KS) 1 at Vester Hassing in 1988. In 2006, the mercury-arc converters were replaced by thyristor converters. The converter of KS1/KS2 uses thyristor valves, 2 three-phase two-winding converter transformers, air core smoothing reactors and triple-tuned AC filters.

Figure 18-8 The Danish power transmission system corridors.



In 1976 and 1977, two HVDC links for the oversea connections named Skagerrak 1 and 2 (SK1 and SK2) were respectively installed between Norway and Denmark (see Figure), each with the capacity of 250 MW at 250 kV DC voltage. The converters were built with thyristor valve technology and the cables connected in a bipolar scheme. A third Skagerrak link with a capacity of 500 MW at 350 kV went into operation in 1993. To reduce the earth current, SK1 and SK2 were converted into monopolar links and connected with opposite polarity to Skagerrak 3 (SK3). The control systems of SK1 and SK2 were upgraded in 2006. A fourth Skagerrak HVDC link was installed by the end of 2014 with a rating of 715 MW at 500 kV. The converter technology chosen for SK4 is Voltage Source Converter (VSC) topology. This is the first time a LCC-HVDC and a VSC-HVDC link are tied together in such a bipolar configuration. The topology combines two very different converter technologies with a sophisticated switching scheme, in order to change the polarity of the DC cable for reversing the power flow. At the SK4 converters, the polarity of the DC cable is swapped between +500 kV to -500 kV according to the power direction. It will also be possible to operate each pole in monopolar mode with ground return during maintenance or if a failure occurs. The converter of SK1/SK2/SK3 uses thyristor valves, 2 three-phase two-winding converter transformers, air core smoothing reactors and triple-tuned AC filters.

The Kontek HVDC interconnection between Denmark and Germany has a capacity of 600 MW at 400 kV DC, and is the first HVDC interconnection on Zealand (see Figure). The interconnection is a monopolar HVDC transmission across the sea, connecting asynchronous power grids in each country. The upgrade on the control and the protection systems are carried out by ABB by 2016. The converter uses thyristor valves, 3 single-phase three-winding converter transformers, air core smoothing reactors and triple-tuned AC filters.

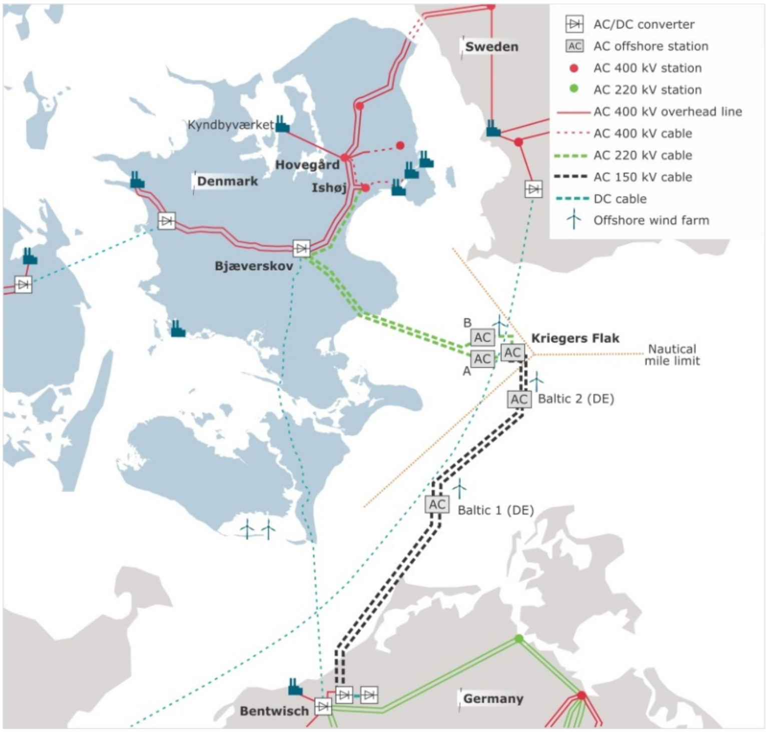
The Storebælt HVDC link was in operation in 2010 (see Figure). The Storebælt HVDC transmission system connects the asynchronous systems between the grid in Jutland/Funen synchronous with the continental European system and the Zealand grid synchronous with the Nordic system. It is a 600 MW at 400kV DC LCC-HVDC link across the Storebælt strait. The HVDC system is configured as a monopolar with metallic return. The converter uses thyristor valves, 3 single-phase three-winding converter transformers, air core smoothing reactors and triple-tuned AC filters.

There are two ongoing projects, installation of Kriegers Flak and COBRAcable VSC-HVDC links (see Figure). Kriegers Flak project is a so called Combined Grid Solution, where offshore wind farms are connected in series to the power grids of two different countries, Denmark and Germany, as shown in Figure . In the Danish side, two offshore wind farms with 200 MW and 400 MW, respectively, connected to 220 kV AC lines with total 600 MW capacity. They are also connected to Baltic 2 (288 MW) and Baltic 1 (48 MW) wind farms via one 220/150 kV transformer (450 MVA) and 150 kV lines (total 400 MW capacity) until Bentwich, Germany, where a back-to-back VSC-HVDC link is connected. In order to minimize the losses, the tap changer on 220/150 kV transformer will raise the voltage at 150 kV side if the power flows from Denmark to Germany and vice versa. The converter at Bentwisch will control the reactive power flow to the low voltage side of the 220/150 kV transformer close to zero. This is first of its kind, that the wind farm connections are also the interconnections of the two countries. This has the advantage that full capacity of the produced power can be transmitted to the country with the highest demand and price, improving the economy of the wind farms. The second advantage is that the connections can be used to transmit the power when the wind power is absence, improving the overall system reliability. The 400 MW at +/-140 kV VSC-HVDC link at Bentwisch is applied for connecting asynchronous systems for the power transmission while control the reactive power at the offshore platform for minimizing the losses. The Kriegers Flak is expected to be commissioned in 2019.

Table 18-6 The Danish HVDC link by 2020. HVDC marked with "*" are under constructions. The LCC-HVDC consumes reactive power (ind.) respected to the active power transmission. The VSC-HVDC links can either absorb (ind.) or inject (cap.) the reactive power.

Name	Tech.	Configuration	Power rating (MW)	Min. power (MW)	Reactive power at rated active power (Mvar)	Number of filters	DC voltage (kV)	Distance of DC lines (km)			Commissioning year
								Submarine	underground	Overhead	
Konti-Skan 1	LCC	Bipolar, ground return with limited power/time	380	11	Ind. 366	3	285	87	--	86	1965, 2005
Konti-Skan 2	LCC		360	9		3	285	88	--	61	1988
Skagerrak 1	LCC	Bipolar, ground return with limited power/time	250	25	Ind. 160	3	250	127	--	113	1976, 2007
Skagerrak 2	LCC		250	25			250	127	--	113	1977,2007
Skagerrak 3	LCC	Bipolar, ground return with limited power/time	500	13	Ind. 260	4	350	127	--	113	1993, 2014
Skagerrak 4	VSC		715	0	Cap/Ind. 85		500	140	104	--	2014
Kontek	LCC	Monopolar, ground return	600	18	Ind. 286	3	400	52	119	--	1995, 2016
Storebælt	LCC	Monopole, metallic return	600	18	Ind. 348	4	400	56	56	--	2010
*Kriegers Flak	VSC	Back-to-back	400	0	Cap./Ind. 100	0	+/-140	--			2019
*Cobra	VSC	Symmetrical monopolar	700	0	Cap./Ind. 230	0	+/-320	325			2019

Figure 18-9 The Kriegers Flak project Combined Grid Solution.



The COBRAcable is another international project (see Figure). A new 700 MW at +/- 320 kV VSC-HVDC link will be built between Eemshaven, Netherlands and Endrup, Denmark. The Modular Multilevel Converter (MMC) technology will be applied in this project. It has a symmetrical monopole configuration, where two high-voltage conductors, operating at +/- 320 kV, with only a single converter at each end. The converters are earthed via large impedance and there is no earth current. Thanks to the MMC technology, COBRA cable does not require any filter. In addition, it can absorb/inject 230 Mvar reactive power from/to the system. The VSC-HVDC link can be operated as a STATCOM to only control voltage/reactive power without transmitting the active power. This is a useful feature as fewer and fewer conventional power plants will be in service in the future Danish transmission system. Consequently, the reactive power resources for the voltage control will be reduced. The reactive power from COBRA cable is therefore highly demanded. The COBRA cable will be commissioned in 2019.

Flexibility guarantee measures

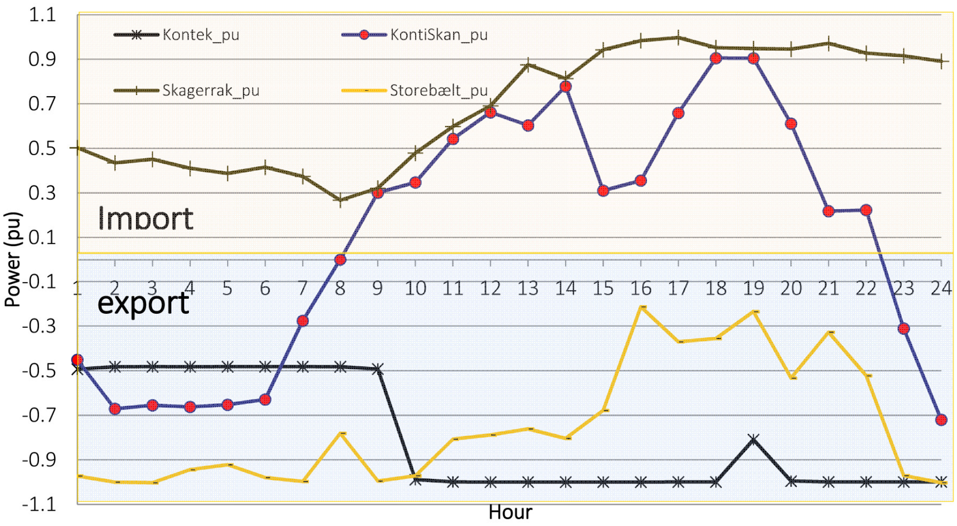
Ensuring the high security of supply is the core task of Energinet. Many functions are implemented on the Danish HVDC links that not only transfer the power between different areas but also provide the ancillary service. The power schedule on the HVDC links are made via the markets and finally realized through the centralized dispatch system. The Reactive Power Controllers (RPCs) in the Danish system are applied to coordinate the grid components with the HVDC converters, ensuring the HVDC functionalities and the grid requirements compliance. These functions are implemented on the HVDC links to assist the system operators to daily control the whole system in a safe way.

(1) Absolute Power Control

The power flow on the HVDC links are up and down according to the schedule determined by the market. The "Absolute Power Control" (APC) is used to follow a power schedule, which is the normal active power control for an HVDC link. After specifying target power values (MW) and a ramp rate (MW/min), the HVDC link will regulate the power towards the target value with the ordered ramp rate. The target values can be with sign or absolute values combined with power direction.

At Energinet the power schedule is loaded into a dispatch system in the control center and new APC orders are sent to the HVDC links via SCADA. It is also possible to upload a power schedule to the HVDC control system directly[116]. The resulted power loadings on the HVDC links are presented in Figure as an example.

Figure 18-10 The normalized hourly power on the Danish HVDC links, 2016-01-01 to 2016-01-02.



All HVDC links in Denmark can operate with a ramp rate up to 999 MW/min but the actual ramp rates used for APC is much lower. For example, the ramp rate on the HVDC links

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[116] It is now only possible in the new control system for Kontek HVDC link. However, Energinet is not using this function, as the set-points are dispatched from DPS system (operational planning system).

between Denmark and Norway is currently 30 MW/min. It is constrained by the system frequency control and the voltage control requirements.

(2) Delta Power Control

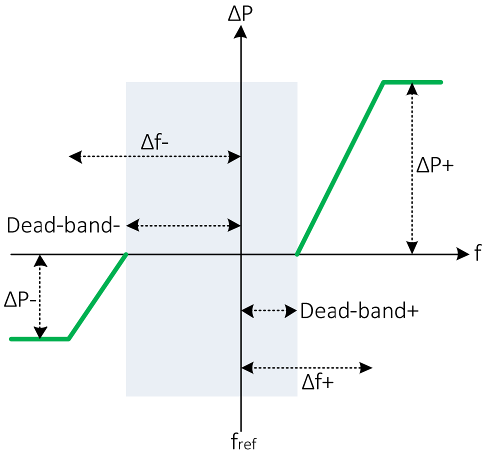
All HVDC links in Denmark have 4 "Delta Power Control" (DPC) orders with fixed delta values (typical between 10 and 100 MW in each power direction) and a ramp rate (typical 500 MW/min). It is updated every 5 minutes, can only be ordered from the Master station.

The operator in the control center can activate each of these four DPC orders if the actual power situation in the AC grid requires deviating from the power schedule for the HVDC links. The DPC orders are also used during testing because it is safe for the operator to send a DPC order than an APC order, avoiding unexpected mistake inputs. DPC orders can be given even during the APC is ramping the power. In that case the ramp rate of APC is overruled by DPC.

(3) Frequency Control

Frequency Control (FC) can give an additional contribution to the actual power order based on the frequency deviation measured in the converter stations. FC can be used for Frequency Containment Reserve[117] regulations. The additional power contribution from a converter station is proportional to the frequency deviation if the deviation is outside a predefined dead-band, as shown in Figure . The total additional power contribution is limited by a predefined maximum quantity. The settings for over/under frequency can be set individually.

Figure 18-11 The active power change adjustments proportional to the frequency deviations over the dead-band in the FC.



(4) Absolut Delta Power Control

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[117] The Frequency Containment Reserve means operating reserve necessary for constant containment of frequency deviations from nominal value in order to constantly maintain the power balance.

The Absolut Delta Power Control (ADPC) gives an additional contribution to the actual power order based on a separate power order from SCADA. The power order is typically updated every 4 seconds and is used for Frequency Restoration Reserve regulation[118] and imbalance netting between the two areas connected by the HVDC link. It can be ordered from the Master, the Slave or from both stations simultaneously. The total additional power contribution is limited by a set maximum in each power direction.

(5) Emergency Power Control – Active Power (EPC-P)

Emergency Power Control (EPC) can give a very fast contribution to the actual power order. EPC-P consists of a number of different entries with individual settings. Each entry can be activated by one or more activation modules with different criteria based on local measurements (e.g. over/under frequency) or by a digital input from e.g. system protection. The settings for the entries and the activation modes are shown in Table .

Table 18-7 The settings for each entry.

Settings	Description
Direction	Power direction of the power change for the entry
ΔP/P	Select if power order for the entry is an delta power or a final value
Power order	Power order for the entry (delta power or final value) in MW
Ramp rate	Ramp rate for the entry in MW/s
Time delay	Time delay from activation of the entry starts regulating the power (normally set to 0)
Entry enabled	Enable/disable the actual entry. Only enabled entries will regulate the power
Priority	If more than one entry is activated the entry with highest priority will start regulating the power. After high priority entry has ended regulation, entries with lower priority may take over

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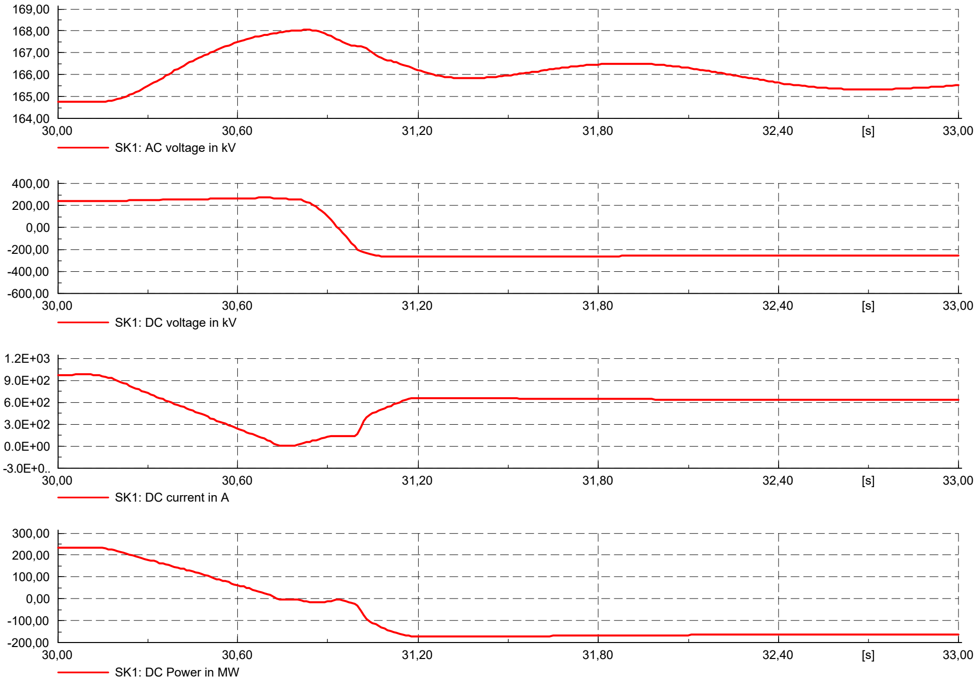
[118] The Frequency Restoration Reserve means operating reserve used to restore frequency to the nominal value and power balance to the scheduled value after sudden system imbalance occurrence. Full activation time and deactivation period shall not be more than 15 minutes.

Table 18-8 The settings for each activation module.

Settings	Description
Activation type	Analogue measurement or digital input
Activation value	Value for activations (over/under frequency, frequency difference, over/under voltage, over current)
Drop-off value	Value for deactivation
Pick-up time	The activation criteria must fulfill the set time before the entry is activated
Drop-off time	The drop-off criteria must fulfill the set time before the entry is deactivated

Figure 18-12 The measurements of an incident of EPC-P on Skagerrak 1.



The EPC-P was activated on Skagerrak 1 HVDC link (SK1) for the fast power reserve, and the measurements are recorded, as shown in Figure . The power on SK1 was reversed within 1 sec, where the DC current is ramped down to the minimum for changing the polarity and then ramped up to a certain level. The ramp rate is about 400 MW/sec. The AC voltage increased as the DC current ramped down, which was close to the maximum allowed voltage, 170 kV in this case. The polarity change took about 1 sec.

(6) Runback

Runback is used for limiting the power to the set value (independent of the power direction). It can be activated by internal/local measurements (e.g. overloading of components) or be activated by a digital input from e.g. system protection. Once activated, if the actual power order is higher than a threshold, the power will be ramped down with the set ramp rate. It is widely applied for Special Protection Scheme in Denmark.

(7) Power Oscillation Damping Control

The Power Oscillation Damping (POD) control can provide an additional contribution to the actual power order in order to damp low frequency oscillations in the connected AC grid. The contribution can be calculated internally in the HVDC control system or calculated/measured externally and send as an analogue signal to the HVDC control system. Energinet is not using POD at the moment.

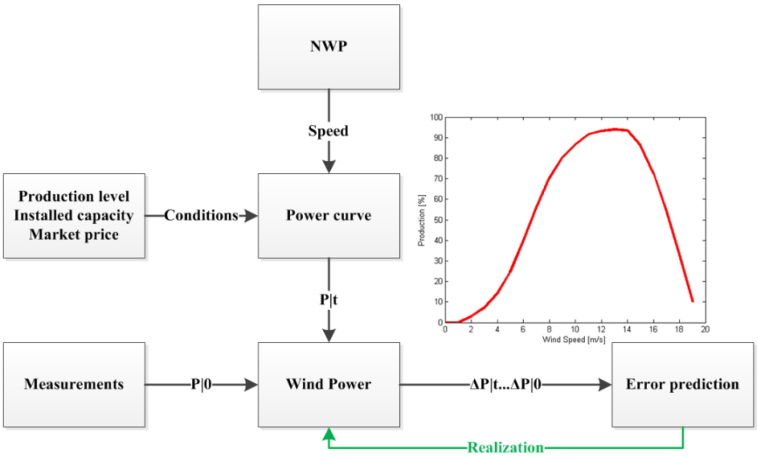
(8) Dispatch

Energinet continuously predicts the hourly electricity consumption for the next day. Forecasts for the coming wind power generation are based on two categories of information – input from a model calculation (Numerical Weather Prediction – NWP), and online wind measurements as the delivery hour approaches, as shown in Figure. Denmark is divided into 25 areas for the purpose of the model calculation. The forecast for wind power generation in each area based on input parameters such as wind speeds, wind turbine generation data, installed capacity and expected electricity prices. The forecast is calibrated using historical wind data (an aggregated power curve in each area), and adjusted considering the operational constraints, e.g. to reflect the fact that lower electricity prices will reduce the wind power generation being offered for sale.

As the delivery hour draws near, the forecast can be significantly improved using on-line wind speed measurements from the anemometers installed at about one third of the Danish wind turbines. Using online wind speed measurements, the forecast can be updated at five-minute intervals in each of the 25 areas. The aim of the online measurements is to estimate the "future error" of the model calculation, in order to obtain a more accurate forecast – the "online forecast".

Energinet prepares a similar solar power forecast in order to provide a total picture of the fluctuating electricity generation for the coming hours. In addition, the forecast system at substations is under installations, which is expected to provide more meaningful predictions of the power flow in the transmission grid.

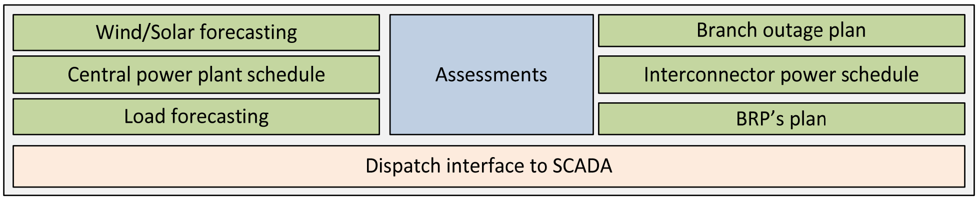
Figure18-13 The wind power forecasting system in the national control center in Denmark.



Energinet control center takes the responsibility for balancing the power during the last hour before the delivery hour. The control center must assess the imbalance between consumption and production for the coming hour, and a number of operating plans and forecasts are used for this purpose. The control center receives operational plans from the balance-responsible parties (BRP) for production. They are required to regularly submit production plans for their plants, so the control center can always work with the latest information.

Before the dispatch, the operators need to perform a set of assessments e.g. N-1 analyses. The assessments are automatically carried out periodically. Possible adjustments could be made on the dispatch plan to avoid the cascading events after a contingency. The operations plans and forecasts are updated regularly leading up to each hour of delivery in order to minimize imbalances before they arise during the moment of delivery. This reduces the uncertainty linked to unpredictable weather as well as the wind and solar power production. All the operational plans are collected in the dispatch system, as shown in Figure18- . The dispatch schedule can thus be made. It has 5-minute intervals. As mentioned, the power schedule of the HVDC link is uploaded from such dispatch system, periodically send to the HVDC links via SCADA system.

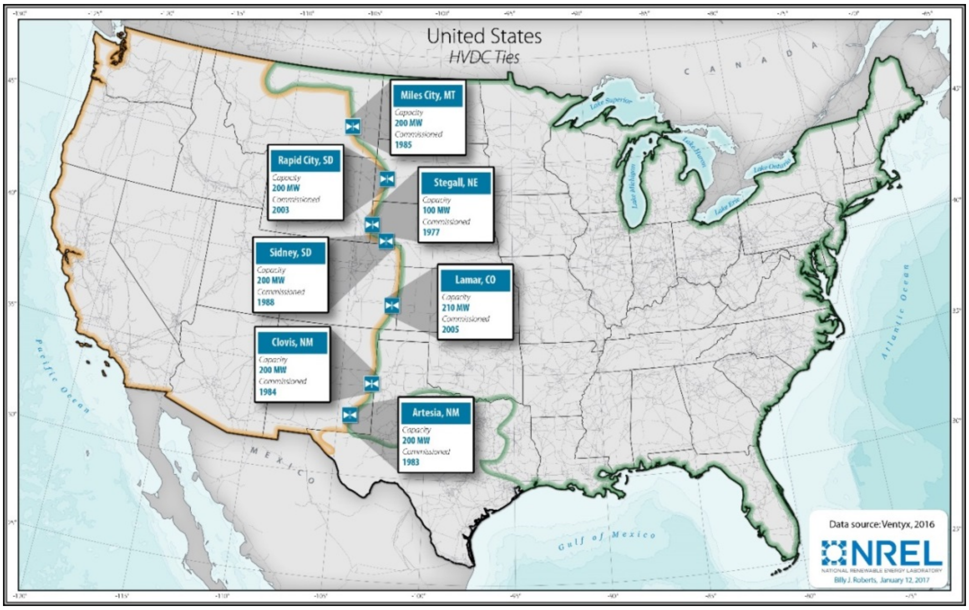
Figure18- 14 The dispatch system of the Danish national control center.



US experience

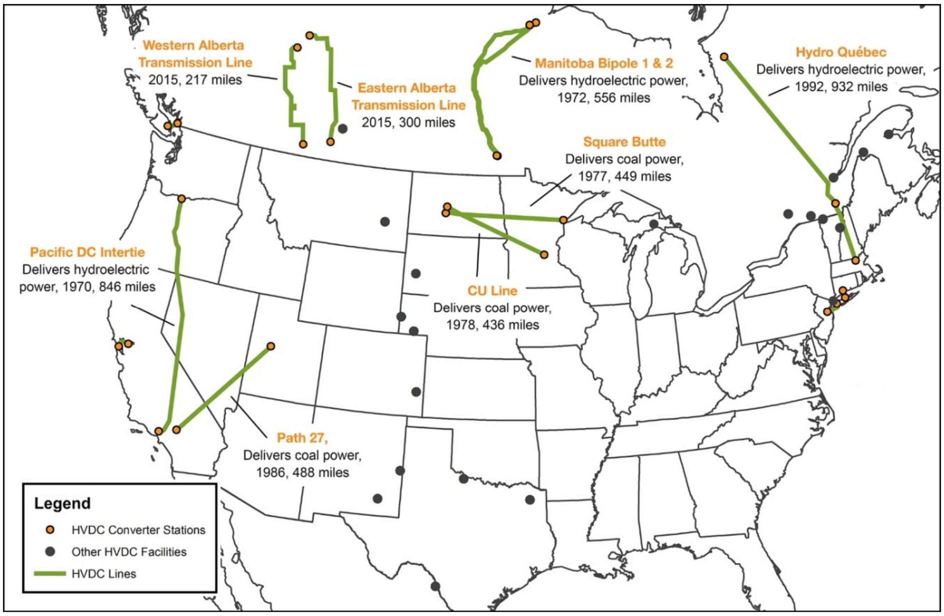
The U.S. electric grid has been considered the largest machine the world has ever built and part of the greatest engineering achievement of the 20th century more than 7,300 power plants through nearly 160,000 miles of high-voltage power lines and millions of low-voltage power lines and distribution transformers. The U.S. power system is made up of three main interconnections, which operate largely independently from each other and have limited power transfer between them. The Eastern interconnection covers the area east of the Rocky Mountains and a part of northern Texas. The Western interconnection encompasses the area from the Rockies west. The Electric Reliability Council of Texas (ERCOT) covers most, but not all, of Texas. The ERCOT interconnection is linked to the Eastern interconnection via two DC lines with a total capacity of 800 MW. The Eastern and Western interconnections are connected with a total of seven back-to-back high-voltage direct current (HVDC) ties with a capacity of 1.4 GW (Figure). This electricity flow is very small, considering the Easter interconnection is home to 700 GW of generating capacity. The ERCOT and Western interconnections are not linked.

Figure 18-15 HVDC ties between the Eastern and Western Interconnections. Source: NREL.



HVDC deployment in United States has been relatively small compared to the overall system, with about 20 transmission projects in the United States and a total of more than 35 HVDC transmission facilities across North America (Figure). Europe and Asia, by comparison have relatively more developed HVDC markets.

Figure 18-16 HVDC Deployment in North America.



HVDC deployment faces many technical, economic, and regulatory challenges. For example, managing the loss of an extremely high capacity HVDC link for large power imports into an area can be difficult. The HVDC converters are costly and can create power quality issues (harmonics), and multi-terminal HVDC systems require expensive communication systems. Many utilities in United States have a lack of familiarity with HVDC operations and maintenance practices. Historically, HVDC power electronics and controllers have had shorter lifetimes than high-voltage AC assets. Each HVDC application requires thorough technical and economic analyses to determine whether HVDC or high-voltage AC makes the most sense for any geographic region in the United States (both onshore and offshore). Also, lack of interoperability and standardization for HVDC technologies has negative impacts on HVDC equipment and operations and maintenance costs.

Despite the above limitations, demand for HVDC transmission in United States is growing and following global trends that favor HVDC. Increasing levels of variable renewable penetration in all U.S. interconnections is one of the main drivers for HVDC growth. It is especially useful for the integration of large-scale solar and wind generation, which are typically far from the load centers and need long-distance transmission, given the distance-cost relation mentioned above. And increasingly many proposed wind plants are at remote offshore sites. An example is the Atlantic Wind Connection, a proposed undersea transmission cable running from New Jersey to Virginia that would deliver up to 6,000 megawatts of offshore wind energy. Its first phase is estimated to come into service in 2020–21.

Another driver for HVDC adoption is reliability. Electricity customers around the world—including those in North America, Europe, and Asia—are experiencing more blackouts and brownouts. The most recent major U.S. blackout in 2003 affected 50 million people in eight states and Canada. HVDC can help reduce the spread of such large-scale disturbances by providing a buffer between regions. With conversion electronics, HVDC provides an opportunity to effectively manage the power grid by controlling the magnitude and direction of power flow, therefore increasing stability in the transmission grid. Using VSC-HVDC for transmitting variable renewable generation has added benefits because VSC offers good power quality (sinusoidal currents) with minimum filtering on the AC side. Its capability to control real and reactive power on the AC side instantaneously and independently allows it to function as static VAR compensator (up to its mega-volt ampere [MVA] rating capability) in addition to transmit power.

In the United States, building new transmission lines becomes more difficult and expensive with rising land costs, legal, and other barriers in permitting. The need to build new transmission lines can be offset by using HVDC to increase capacity on existing transmission lines. Converting AC lines to DC operation can increase capacity as much as constructing one or more AC lines. Also, HVDC technologies create possibilities for long-distance underground transmission utilizing the existing right-of ways for transportation and other infrastructure.

Other challenges with HVDC in the United States include:

- Lack of adequate valuation and analyses methodologies
- Insufficient software tools, models, and data
- Need for stakeholder education, outreach, and workforce development
- Need for more research, development, and standardization
- Need for demonstrations and test beds
- Need for enabling policies, regulations, and cost allocation for interstate transmission projects

U.S. DOE and private energy sector are participating in many international HVDC initiatives (e.g., DESERTEC, Friends of the SuperGrid, North Seas Countries Offshore Grid Initiative, and the Council on Large Electric Systems - CIGRE). Participating in these initiatives allows the United States to learn best practices from Europe and China. Technology-based best practices can be transferred, but the regulatory environments are decidedly different. Furthermore, other countries typically have a single entity that has jurisdiction over an entire project, whereas the United States has a state-by-state approach for transmission, which presents additional challenges.

European experience

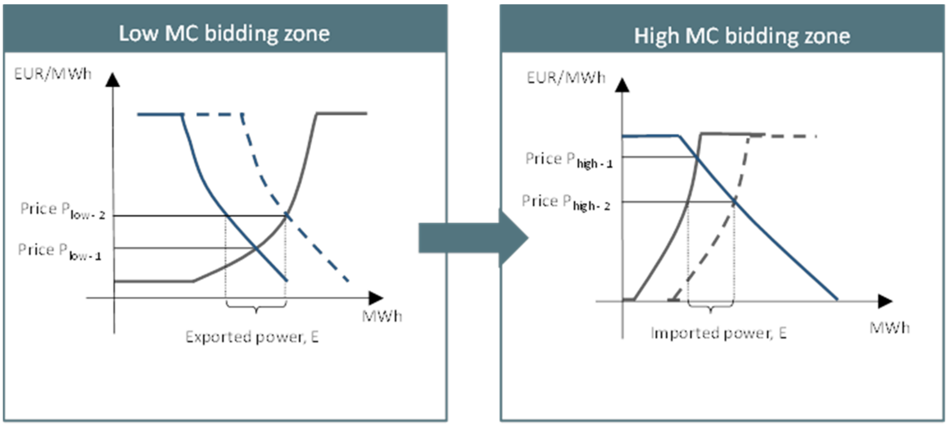
The status of interconnectors in the EU is presented in the following section. It is described which stakeholders are involved and how interconnectors are used. The following section aim to show lessons learned from the chosen mechanisms and market structures in the EU, which could be useful for China. It needs to be considered though the initial situation, the market and sector setups in EU differ from China significantly. In the European system, it is aimed to develop the common coupling markets. The experiences of it can be transferred to China, in which the most important issue is the functionalities of the power markets, clear roles and clear tasks of the market participators. The flexible use of interconnectors is one of the results of having the markets.

Operation of interconnectors

In EU the mechanism of market coupling can be illustrated by a simple diagram in Figure . There is a market consisting of two bidding zones. If no interconnector exists between the zones, the market price can be found in each zone after balancing the generation and the consumption within each zone. In each zone, a merit order of generation and consumption can be found, as illustrated in Figure . The generation units in each zone are sorted according to their corresponding bidding prices in EUR/MWh while the demands are sorted according to their asking prices in EUR/MWh. The intersection represents the energy balance, where the marginal price is determined.

Having no interconnectors would lead to different prices in the zones, as illustrated in Figure , Prices P_{Low-1} in the left figure and P_{high-1} in the right figure are the prices that secure a balance between demand and supply in each zone without interconnectors. The difference in prices shows that the market prices differ between the zones, i.e. in the left zone the consumer pays less money than the one in the right zone while the producer earns less in the left zone than the one in the right zone. If an interconnector is included in between, the cheaper power will be exported from the low price bidding zone (left figure, see Figure) to the high price bidding zone (right figure), thus more production is needed in the low price bidding zone and less generation is required in the high price bidding zone. This would lead to prices P_{Low-2} and P_{high-2}, (see Figure).

Figure 18-17 Pricing and dispatching with and without an interconnector (*Energinet)*



Having a large geographical market area via market coupling increases efficiency and the integration level of RE, because more resources can be applied to overcome the variability of the RE outputs. When working in combination, the sum of individual generation profiles provides more stable generation characteristics, which eases the integration of fluctuating RE generations. This will also increase the average capacity credit of RE. Capacity credit is a "firm" capacity as a fraction of total installed wind or photovoltaic power capacity that can be accounted to secure the yearly peak demand.

The same concept is valid for the load pattern, since there are diverging peak demand periods between member states and even provinces within the member states. The generation capacity can be applied more efficiently in large market, e.g. reduce the backup generation and balancing energy capacity. The average peak load of integrated market zones is lower than the sum of the peak loads of the individual zones.

In a functioning market, an adequate liquidity and a sufficient number of market actors are needed in order to enable a competitive market environment, which leads to reduction of the total cost of the electricity system.

Prices can differ between different bidding zones. The Nordic market is divided into several bidding zones (see Figure). The bidding zones delimitation reflects where the major congestions occur in the Nordic power grid.

Figure 18-18 Bidding zones in the Nordic day-ahead market (Nordpool Spot)

Note: The red lines indicates the delimitation of bidding zones

In bidding zones, the price and quantity of each production unit are calculated by hour. However, the calculation for a specific bidding zone is not done independently of the calculation for the other bidding zones. The market is cleared for all bidding zones simultaneously, where generations and consumptions are dispatched for all zones according to the merit order principle. For a market with e.g. two bidding zones, the merit order dispatch of generators in one zone is performed taking into account that generators with lower cost in the other zone. To serve load in the cheapest possible way in a given bidding zone, the merit order includes generators of other bidding zones.

Interconnectors play a central role in this scheme, which connects different bidding zones. It is thus possible to obtain a cross-zonal merit order in the common market. The key point is to include interconnector capacity in the market clearing, ensuring simultaneous cross-zonal dispatch. The market coupling (see above) basically secures that the interconnectors are properly applied for transmitting power from low-price zones to high-price zones. Transmission bottlenecks have to be taken into account, which results in different prices in bidding zones.

Operation of interconnectors: explicit and implicit auctions

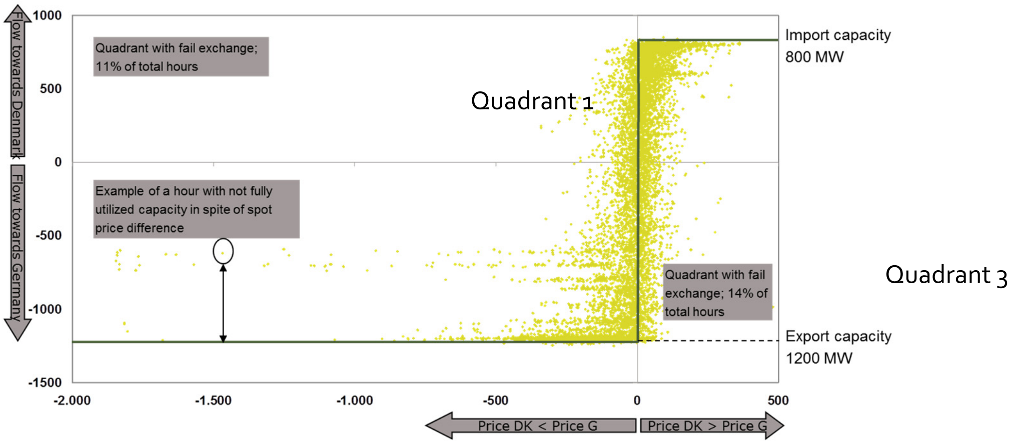
The scheduling of the daily power dispatch reflects the demand and production quantities in the given market areas. When the dispatch scheduling in neighbouring power markets (bidding areas) is done separately or independently of each other - as if there is no interconnection between them - then the demand in each area must be covered by the production in this given area. Having interconnectors between the neighboring power systems (bidding areas) offers the opportunity to balance the power using the cheapest possible measure within connected areas. The question is how to use the interconnector in a proper way.

(1) Explicit auctions of interconnector capacity

Before different neighbouring power markets (bidding areas) in Europe were coupled, the interconnector capacity was scheduled through explicit auctions. The right to use the interconnector capacity between neighbouring bidding areas was auctioned independently from the power traded in the day-ahead spot markets in the adjacent bidding areas. The capacity was auctioned in portions through annual, monthly and daily auctions. Since the transmission capacity was auctioned prior to and independently from the power trading in the day-ahead market in the bidding areas, the interconnector capacity auction was done without information about the supply and demand quantity. So the prices for electricity and for interconnector capacity were not linked. This lack of visibility regarding the relative price difference between the markets resulted in an inefficient utilization of the interconnectors as the flow of power frequently went from a higher price area to a lower price area.

The figure (see Figure) below illustrates the problem with explicit auctions. It shows the flow over the border between Denmark (DK West) and Germany in 2006 before price coupling between the two markets was introduced. It shows exchange of energy in the "wrong" direction in 25 % of the hours of the year (14%+11%). Power flows from an area with higher market prices towards an area with lower power market prices. In Quadrant 1, there is power flow from Germany to Denmark despite power price (and thus production cost) are lower in Denmark in these hours. In all these hours cheaper production is substituted by more expensive production. A similar situation is shown in Figure Quadrant 3, where relatively expensive Danish power production is exported to Germany and substituting actually cheaper production there. Both situations represent social-welfare loss due to the improper market design for the use of interconnectors.

Figure 18-19 Power exchange between Denmark and Germany in 2006 (8760 hours), when explicit auctions were still used in the day-ahead market (Energinet 2017)



(2) Implicit auctions and scheduling of interconnectors

Within implicit auctions, the producers/consumers in each bidding area send their power supply/consumption bids/inquiries to a common platform, where the common algorithm would clear the joint market to determine the schedules of generations/consumptions and interconnectors in these areas. With this approach, the interconnector capacities are taken into account as constraints in the market clearing algorithm. The prices of each hour for the following days are thus determined after market clearing. Hourly schedules of generators, demands and interconnectors are found as well.

Implicit auctions ensures production flows from the low price area to the high price area, so overall demand is met at a lower marginal price by substituting more expensive production with cheaper production via interconnectors.

Power transmission from the low to the high price areas has the following effects:

- The lower price area will have larger production due to the export and the power prices will increase (benefiting the producers, but a disadvantage for the consumers in this area).
- The higher price area will have a lower production due to import and the power prices will decrease (benefiting the consumers, but a disadvantage for the producers in this area).
- Characteristics of implicit auctions:
- The interconnectors are dispatched and used in a dynamic way – changing the power flow from one area to the other many times a day determined by the market.
- The interconnectors are used in the most efficient way by always ensuring that demand is met by the cheapest possible generation.
- An overall social welfare is obtained when power is transmitted from low to high price areas.

(3)Planning and financing new interconnectors

The most obvious market indicator for the need of more transmission capacity between two bidding zones is a high price difference between the zones. If the zones are already connected, price differences indicate congestions on the present transmission line. If the two bidding zones are not connected, price differences give a signal that it might be beneficial to build an interconnector. A price difference of X Euro/ MWh between the bidding zones equals the marginal value of extending the transmission capacity by 1 MW.

In Denmark, the Danish TSO Energinet carries out investment analyses for new interconnectors on basis of socio economic welfare criteria. The important criterion for approving an investment is a positive business case for Denmark and/or the region. Benefits must be larger than cost for the business case to be approved. The analyses take as basis Energinets presumptions for the future power systems in Denmark and neighbouring countries. The following elements are part of the evaluation:

Changes in socio economic benefits for Denmark and the region incurred by the transmission project:

- Trading benefits: Changes in consumer surplus, producer surplus and congestion rents.
- System supporting services: Reduced cost of e.g. system supporting grid components
- Transit compensation: Compensation from neighbouring countries for transits
- Security of supply: Value of project with regard to securing the supply
- Regulating power: Value of increased opportunities for balancing services between market areas
- Other elements: e.g. subsidy from EU funds

Changes in socio economic costfor Denmark:

- Cost due to changes in transmission losses
- Investment: Cost of investment including assumptions for interest rate development
- Operation and maintenance: Cost of operation and maintenance during the expected lifetime
- Changes of reserves: cost/benefits of increased/reduced reserves
- Cost of non-availability of interconnector: reduced trade benefits

Figure 18-20 Trading benefits. Congestion rent and total trading benefit (Energinet)

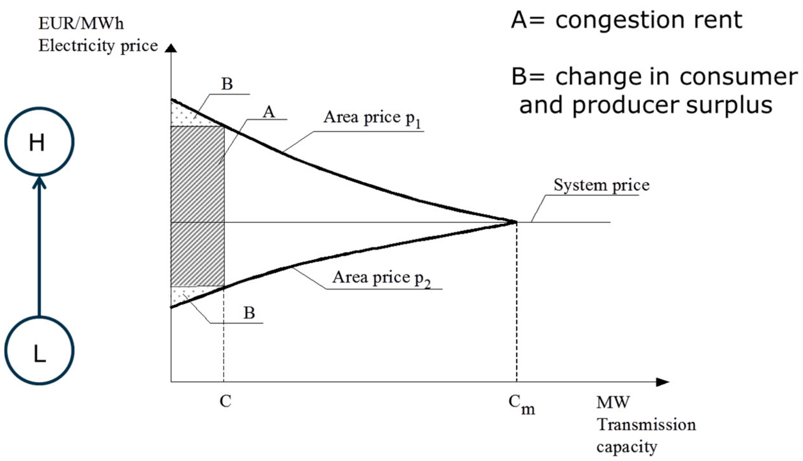
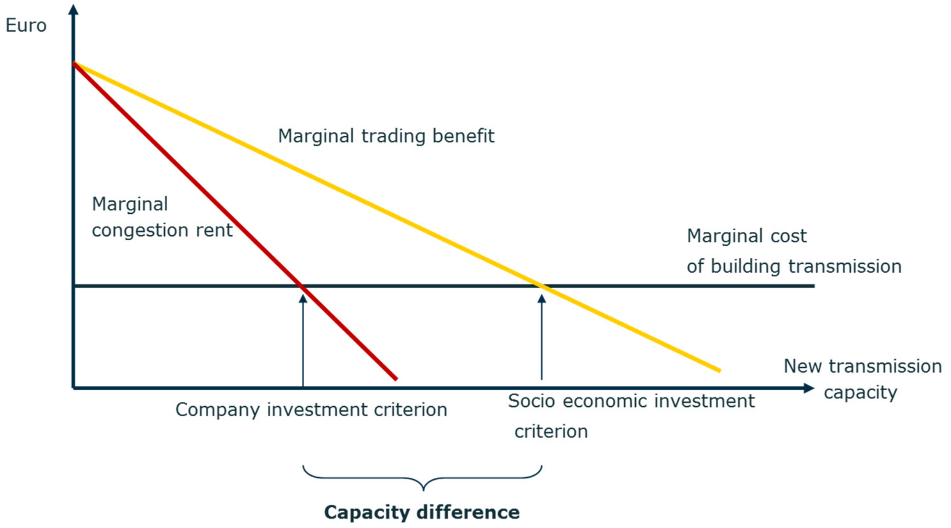


Figure defines and illustrates some important concepts in regard to trading benefits in an example with only two areas. "L" indicates a low price area and "H" a high price area. The interconnection capacity is "C".

Power transport from L to H involves a decrease of market price in H and increase in L. The congestion rent is represented by A. The two areas B are the net changes in producer and consumer surplus in high price area (upper B) and low price area (lower B), respectively. The congestion rent is the money consumers pay to grid companies or generation companies, and would not be paid if the transmission system would be congestion-free, which is considered a macroeconomic advantage. The congestion rent is calculated as the exchanged power multiplying the price difference between the two areas.

Figure18- illustrates the marginal congestion rent and the marginal (socio economic) trading benefits with increasing interconnector capacity. In addition, the marginal cost of building the interconnector is shown. The optimal transmission capacity in the socio economic analysis is the crossing between marginal cost and marginal trading benefits (neglecting other benefits than trading benefits). For a private investor, who only has income from the congestion rent, the optimal capacity is less. The optimal capacity is shown at the crossing of marginal congestion rent with marginal cost.

Figure18- 21 Criteria for investments (Energinet)

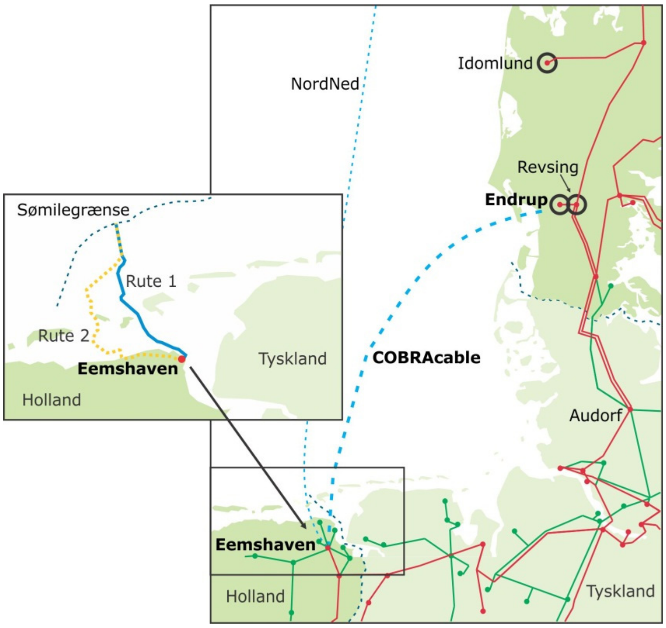


To decide whether a new interconnector has a benefit to society, Energinet uses market modelling. The principles described above are extended to encompass many areas covering Northern Europe. This is done in a market model which simulates the European day-ahead market hour per hour through the year. Calculations are made for several future years (for example 2020 and 2030). Simulations are made excluding and including the proposed project. The trading benefits are estimated by subtracting the results of the two corresponding simulations. Market models calculate the "market values" of a given investment based on demand, generation, prices and power flows. It is a fundamental model of the market differentiating in generating units (thermal, hydro, wind, PV, etc.), power demand and transmission lines.

Case Study – Cobra interconnector between Denmark and the Netherlands

The Cobra interconnector is a 700 MW HVDC cable from the western part of Denmark (substation Endrup) and substation Eemshaven in the Netherlands, see figure 3.1. Presently the interconnection is under construction and will be commissioned in 2019. The cable is the result of cooperation between the TSOs Tennet NL in the Netherlands and Energinet in Denmark.

Figure 18-22 The Cobra DC interconnector between Denmark and the Netherlands.



Components:
Converter-station in Jutland
22 km cable on land in DK and NL
307 km sea cable
Converter-station in NL

Investment Cost
~ 4.8 bn. DKK
~ 0.6 bn. Euro

The evaluation is based on Energinet's "presumptions of analysis" for the future development of the Danish and European power systems. The elements of the socio economic business case are shown in table 3.1. The conducted analyses show, that trading benefits and contribution to security of supply (generation adequacy) are the major elements of the economic benefits. Much of the evaluation in a business case is based on market models which are used to simulate the markets with and without the investment in question. By comparing the results the changes caused by the investment can be calculated. Based on demand, generation, prices and power flows etc. the "market values" of a given investment can be calculated. For Cobra the present value of all benefits and costs (cf. table 3.1) for the expected life time of 30 years is estimated. As benefits are higher than costs, the investment in Cobra can be recommended from a socio economic point of view.

Table 18.9 Elements of socio economic business case of Cobra

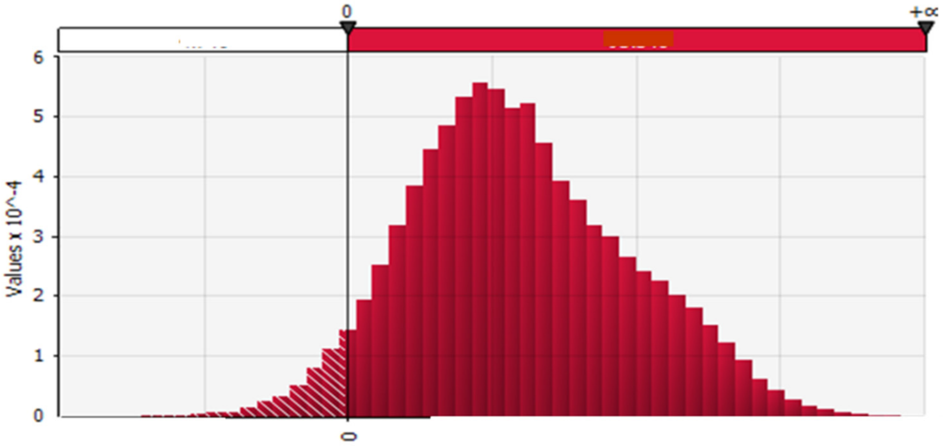
Elements of socio economic evaluation
Socio economic benefits
Trading benefits - Changes in consumer surplus, producer surplus and congestion rents on interconnectors for Denmark is calculated through modelling with Energinet's market models
System supporting services - Value of system supporting services: Reduced costs of forced running of thermal units and reduced investments in system supporting grid components.
Transit compensation - Transit compensation covers payment to Energinet from other countries for transit from of power through the Danish grid.
Security of supply - Value of change in security of supply and of securing adequate generation capacity. If the capacity of thermal power plants is reduced in Denmark the Cobra connection will contribute to keeping the security of supply (generation adequacy)
Regulating power - The value of increased opportunities for balancing between market areas, e.g. through the regulating power market
Other topics - Contribution from EU funding (Energy Programme for Recovery). - Impact on other agreements (SK4- agreement with Statnett)
Socio economic costs
Losses - Costs of changes in electrical losses in the Danish grid (including Cobra).
Investment - Cost of investment (Cobra)
Operation and maintenance - Costs of operation and maintenance through expected life time
Change of needs for reserves - Increased/reduced costs of increased/reduced need of reserves
Non-availability of Cobra - Cost of non-availability of Cobra (reduced trading benefits)

It is important to evaluate the robustness of the investment´- will the investment still be advantageous if the presumptions of major drivers for the investment change? To answer that important question a number of sensitivity analyses are carried out. From model simulations it follows that especially two factors are important for the Cobra business case:

- The development of transmission capacity in northern part of Germany for southern power transmission. If the present bottlenecks in the German transmission system are removed earlier than expected, then the business case for Cobra will be reduced. This is because Cobra "competes" with the alternative route of power flow between Denmark and Germany.
- The technology development of wind turbines in direction of generating the same yearly production with lower installed capacity (e.g. this can be done by using larger rotors in proportion to installed capacity). The trend in this direction will reduce the peaks of wind generation and thereby the need for balancing via interconnectors. Also the price differences at each end of an interconnector may tend to be reduced.

The risk evaluation is carried out by setting numbers on these two risk components as well as other factors. E.g. it is assumed that the expansion of the transmission grid in Germany is increased by X MW compared to the base case, and that the probability of this taking place is estimated to be Y %. By conducting such a quantitative approach for all important factors and afterwards running a Monte Carlo simulation including all events and their probability, it is possible to get a picture of the total risk of the project. The result could be that the probability of a positive business case is larger than Z % (see figure 3.2). In the case of Cobra the value of Z was acceptable and the investment was approved by the Danish Energy Ministry. (Also Cobra was approved by the Dutch Energy Ministry).

Figure 18-23 Conceptual Illustration of results of a Monte Carlo simulation. Probability density function of net present value of Business Case (illustration only). The area of the density function for values greater than zero is the probability of the Business Case being positive.



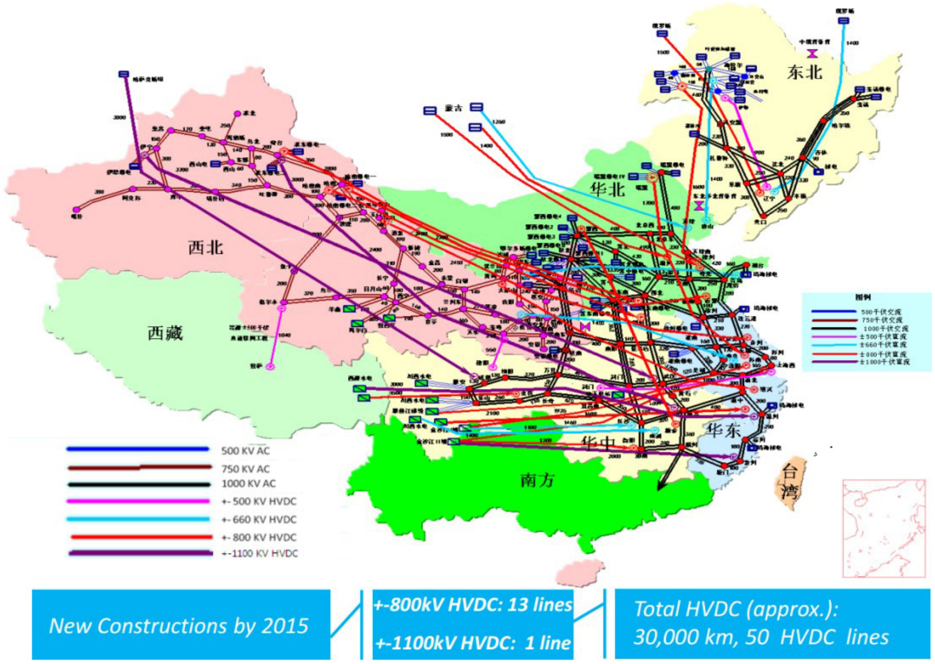
China

Current progress of HVDC in China

By 2015, total 50 HVDC lines are constructed in China, which transmit power over 30,000 km. These HVDC links are mainly used for long distance transmission and asynchronous systems connections. New UHVDC projects are undertaken, including thirteen +/-800 kV and one +/- 1100 kV HVDC links, as shown in Figure . The mixed UHVDC, HVDC and HVAC will compose the Chinese backbone transmission system.

In China, the power flow directions on the HVDC links are rarely changed, as the power consumption at the HVDC receiving ends are concentrated in the eastern China while many power generations at the HVDC sending ends are located in the western and northern China. The power of a HVDC link is adjusted only 1-4 times per day. In Figure , a typical power curve of the Chinese HVDC link is presented. The power ramps up and down as the power set-points changed, following a ramp rate.

Figure 18-24 The planned Chinese transmission system in 2020



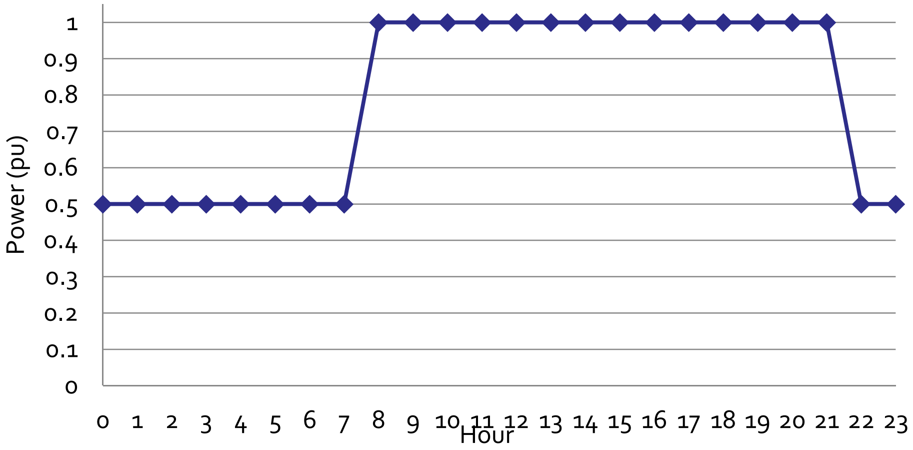
New Constructions by 2015

+-800kV HVDC: 13 lines

+-1100kV HVDC: 1 line

Total HVDC (approx.): 30,000 km, 50 HVDC lines

Figure 18-25 Typical power curve of the Chinese HVDC link

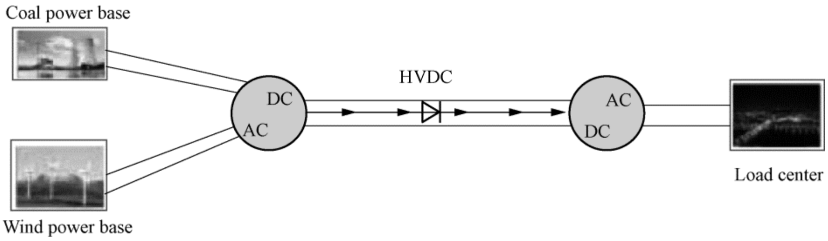


As the HVDC technology is suitable for long-distance and large-capacity power transmission, it becomes one of the mainstream technologies discussed with respect to large-scale renewable energy transmission. The traditional HVDC system of the existing projects in China is operated in the constant power mode (though DC power can be adjusted manually as planned). The HVDC system can also be adjusted on line (not manually) according to renewable energy output including wind power or particular control objectives to make its operation more flexible, which is also called variable power operation, but such an operation mode is still being tested in China.

(1) Constant power operation mode

This operation mode mainly utilizes thermal power to compensate the fluctuation of wind power to realize the basic constant power in the HVDC transmission.

Figure 18-26 Traditional HVDC Scheme with Wind Power Combined with Thermal Power [7]



Transmission of 1 p.u. wind power generally requires compensation of 1.5~2.2 p.u. coal power. This means that 10.5GW~15.4GW installed capacity of thermal power plant is required to transmit 7GW wind power (the installed capacity of wind power can be 10GW). Therefore, this mode is subject to following restrictions:

1) Conditions of coal mine. In general, coal resource is normally poor near a large wind power base, which limits the development of the thermal power for compensating the wind power.

2) Adjustment performance of large thermal power plant. This is related to not only the technical economy of coal-fired power plant but also the feasibility of market rules, management and commercial operation.

3) Efficiency and emission of thermal power plant. In order to regulate the fluctuation of wind energy, it is necessary to frequently adjust the output of thermal power plants. It will change the load of the thermal power plant and therefore influences its efficiency and emission level. See Table 4.

Table 18-10 Standard Coal Consumption of 600MW and 1,000MW Generators under Different Load Levels [6]

Load level (percentage of rated capacity)	Standard coal consumption (g/kWh)	
	1,000 MW ultra-supercritical generator	600 MW ultra-supercritical generator
40	306	311
50	298	303
75	287	290
100	282	284

(2) Variable power operation mode

The active power order of the HVDC system is adjusted in the real time according to the fluctuating wind power, to enable consumption of renewable energy in a greater power system. Under the variable power operation mode, one solution is to combine with STATCOM, which is used to compensate changes in the reactive power of the HVDC system caused by fluctuation of active power. The difficulty is to reduce the capacity of STATCOM for economic efficiency. The solution mentioned above has not been applied to any actual project to date.

(3) Voltage Source Converter-based High Voltage Direct Current Transmission (VSC HVDC)

VSC HVDC is characterized by lower harmonic level and smaller converter station volume (compared with traditional HVDC system). It can perform decoupling control over active and reactive power. It is one of the mainstream technologies frequently applied at present, in particular, to connect offshore wind farms, but the transmission capacity of VSC HVDC system is limited by the allowed connecting current of semiconductor component (IGBT).

Challenges Faced by Flexible Operation of HVDC in China

Compared with Denmark, Germany and other countries, China has built dozens of HVDC transmission lines; however, there is still a big gap in the flexible operation of HVDC between China and those countries; in particular, in the adaption to the delivery of wind, solar power and other renewable energy, flexible HVDC transmission has become an important means to ensure the development of high proportion of renewable energy in Denmark, Germany and other countries. The challenges to the flexible operation of HVDC in China are not only technical, but also more systematic and institutional.

(1) The lack of accuracy of wind and solar power output prediction is an important bottleneck

The inherent intermittency and fluctuation of wind power and photovoltaic power generation make the accurate prediction of wind and solar power output become a key to balance the power system, as well as an important reference for dispatching HVDC power transmission;in particular, China's HVDC transmission lines are mostly used to connect large trans-provincial and trans-regional renewable energy bases and load centers; thus, the accurate forecasting of wind and solar power output often directly affects the effective consumption of wind and solar power. Compared with foreign countries, the forecasting of wind and photovoltaic power generation was started late in China; and such forecasting involves meteorology, aerodynamics, statistics, and many other fields; in China, no enough basic data required by the forecasting system has been accumulated; the technologies of monitoring and collecting meteorological information are not mature enough; and the development of prediction methods needs to be improved. At the same time, the uncertainty of wind and solar power in China is more complicated than that in other countries under the influences of resource conditions and geographical location. Therefore, from the experience of foreign countries, the flexible dispatch of HVDC is based on the accurate forecasting of load and generation output; at present, more than 98% forecasting accuracy can be realized in China in terms of short-term and ultra-short term load forecasting; however, the forecasting accuracy of power generation of wind, photovoltaic power and other renewable energy is still relatively low; the large fluctuation of wind and photovoltaic power that cannot be objectively forecasted is bound to cause a great impact on the normal operation of HVDC, which requires the HVDC to balance the compensation at the sending end and control the proportions of wind and photovoltaic power generation; therefore, the lack of accuracy in the forecasting of wind and photovoltaic power output has become an important bottleneck restricting the flexible operation of HVDC.

(2)The inter-provincial interest barrier is the main constraint

The construction of regional electricity markets, promotion of market trading of trans-provincial and trans-regional electricity, and promotion of the optimized allocation of power resources in a wider range are the development requirements of power grid in China. The Document No. 5 issued by the State Council in 2002 clearly states that it is the goal of market construction to establish competitive and open regional electricity markets; the Document No. 9 by the Central Committee of the CPC and the State Council in 2015 and its supporting documents further require the further improvement of trans-provincial and trans-regional electricity trading mechanism. However, at present, the provincial power grids are the main settlement and assessment entities in China and regions and entire state are subject to coordinated dispatch; trans-provincial interest barriers have not been broken, but with the trend of increase, and the regional power grids have been weakened. Even if the flexible operation of HVDC can supply cheap water, wind, photovoltaic power and other renewable energy power across provinces and regions to meet the needs of the electricity demands of load centers and achieve maximum social benefits, the sending province is more willing to sell the high-cost electricity to the outside and retain the low-cost electricity in own province in the face of pressure of downward economy and market carrying capacity. In addition, the electricity with a cheap price will occupy the power generation market of the receiving province and deteriorate the survival environment of power generation enterprises in the receiving province; furthermore, with higher transmission and distribution prices, the flexible operation of HVDC lacks economic basis.

Therefore, current operation of HDVC in China lacks flexibility, which, beyond the technical level, is deeply reflected in the relationship between electricity and economic development, the relationship between central and local interests, etc.; the inter-provincial interest barriers have become the main constraint to the flexibility of HVDC.

(3) The lack of overall optimization of supply and demand market are key factors

China's HVDC is planned by the government, and mostly invested and constructed by power grid corporations. The development of HVDC is mostly used as a channel to allocate trans-provincial and trans-regional resources; although the matching of the power and load at the sending and receiving ends will be fully considered, more attention is paid to recover HVDC construction funds; in addition, the fixed transmission and distribution prices make HVDC lack of enthusiasm of flexible operation and full load operation is greatly expected to accelerate the investment recovery. In contrast, in Denmark and other countries with flexible operation of HVDC, the HVDC planning and construction will be fully integrated into the planning of sending and receiving ends and the investment and construction of HVDC lines are planned through fully considering the overall economic benefits of sending, transmission and consumption, and conforming to the operation of electricity market. Therefore, China's HVDC planning and construction is relatively deficient in evaluating the supply and demand at the sending and receiving ends, and the combination with the market, lacks overall optimization of sending, transmission and consumption. HVDC owners pay more attention to the investment recovery, but cannot guarantee the maximization of interests from the perspective of the whole society. The lack of the overall optimization of the supply and demand markets have also become the key factors that affect the flexibility of HVDC.

Prospect of HVDC development in China

The future HVDC development in China is required to stick to the principles of flexibility and efficiency, reinforce the coordinated planning of HVDC and large renewable energy bases including hydro power, wind power, solar power generation and load demands, emphasize the combination of HVDC investment, construction and market demand, and promote the construction of long-distance trans-provincial and trans-regional power transmission pattern of "West to East Power Transmission, North to South Power Transmission", giving priority to renewable energy and taking coal power as complement in China; gradually break the inter-provincial barriers, accelerate the completion of provincial, regional, and national multi-level dispatch systems, reform the operation mode of electric power dispatch, speed up to break through the forecasting of wind and photovoltaic power, power grid balance, self-adaptation and other technologies, promote the flexible operation of HVDC continuously through a variety of technical supports, and significantly improve the abilities of peak-shaving of power system and consumption of renewable energy; promote the reform of the operation mode of the power system, implement the energy saving and low carbon dispatch mechanism, speed up the construction of power spot market and ancillary power service market, reasonably compensate the power peak-shaving cost, provide a system guarantee of HVDC flexible operation, give full play to the regulating role of HVDC, make efforts to consume renewable energy, and reduce energy and resource consumption and pollutant emissions.

19 Thermal power plant flexibility

19.1 The need for flexibility in the power system

As the Chinese deployment of wind and solar power plants has soared during the past 10 years, it has become increasingly difficult to integrate the power production from the variable power production units. Historically, the operation of the power system which features a large proportion of coal-fired thermal power plants, has not sufficiently adapted to the inherent properties of fluctuating wind and solar power production. Furthermore, the necessary incentives for flexible operation of the thermal power fleet have been absent. Consequently, a large amount of the power production from wind farms and solar power plants has not been used – the variable renewable energy (VRE) power plants have been curtailed. This is particularly the case in the northern regions during the winter season where the obligation to supply of district heating forces combined heat and power (CHP) plants to operate and to have a very high minimum power output.

To address this issue, the 13th Five Year Plan for Power Sector Development targets to retrofit 220 GW existing coal-fired thermal power plants by 2020 in order to increase flexibility. This will be achieved through retrofitting 133 GW CHP units and 86 GW condensing (power only) units. The plan specifies that 215 GW of the capacity should be located in the three northern regions where the need for enhanced flexibility in the power system is most urgent as indicated by the high curtailment levels of wind and solar power.

The approach is to increase the load regulation capabilities as well as enhancing the flexibility using heat storage with CHP units. Through enhancing the load regulation ability the plan aims to obtain 46 GW additional load capability. To support and make full use of the enhanced technical flexibility of the 220 GW coal-fired units the plan also sets out to improve the dispatch system as well as prioritise efficient use of the renewable energy production assets – both in the longer term and in the day-ahead scheduling[vi].

19.2 Thermal power plant flexibility measures

Thermal power plants are already a main source of flexibility through the ability to adjust power output and follow the change in demand level over time. Thermal power plant flexibility is therefore a question of how much and how fast thermal plants can change their output. As the share of variable renewable energy power production (VRE) continues to grow the need for increasingly flexible thermal power plants will increase.

In China most of the installed power capacity is based on coal, which should be able to operate flexibly to accommodate the rising share of VRE. In this section focus is on larger (300 to 1,000 MW units) pulverized hard coal-fired thermal power plants – both condensing plants and CHP plants.

Thermal power plant flexibility is relative low cost and quickly implemented

One of the benefits of enhancing the flexibility of thermal power plants is that it can be done by learning to operate the plants more flexibly or make modest investments in retrofitting the existing assets. There may not be a need to invest in new flexible power plants as it is possible to increase flexibility of existing assets. Besides retrofitting, any new thermal power plants built in the future can, however, also be built with improved flexibility characteristics over the historical norm, at relative limited additional costs. Enhanced thermal power plant flexibility can be implemented quickly as flexibility –often within a year or two. Areas with large and immediate flexibility challenges can be targeted for improving the flexibility of their thermal power plants, which can add considerable flexibility to the local system.

Barriers for enhanced power plant flexibility

The constraints for enhanced flexible operation are often technical in nature, but existing dispatch rules and market incentives are often equally limiting factors, if not even a more constraining barrier for unleashing more flexible operation. Plant owners and operators might also be reluctant to operate the plant in a more flexible manner as wear and tear of plant equipment increases and pushing the current production boundaries may increase the risk of unplanned outages – at least in the transition period until the new production boundaries become the new norm at the plant. Operating the plant beyond the original equipment design values might pose a risk of voiding manufacturers' warrantees and could thereby also be a barrier for introducing a more flexible operational paradigm. Finally, lack of plant staffs' ability to adapt to new operation practices or under-trained staff can be a key constraint to achieving enhanced flexible operation.

Typical enhanced power plant flexibility measures

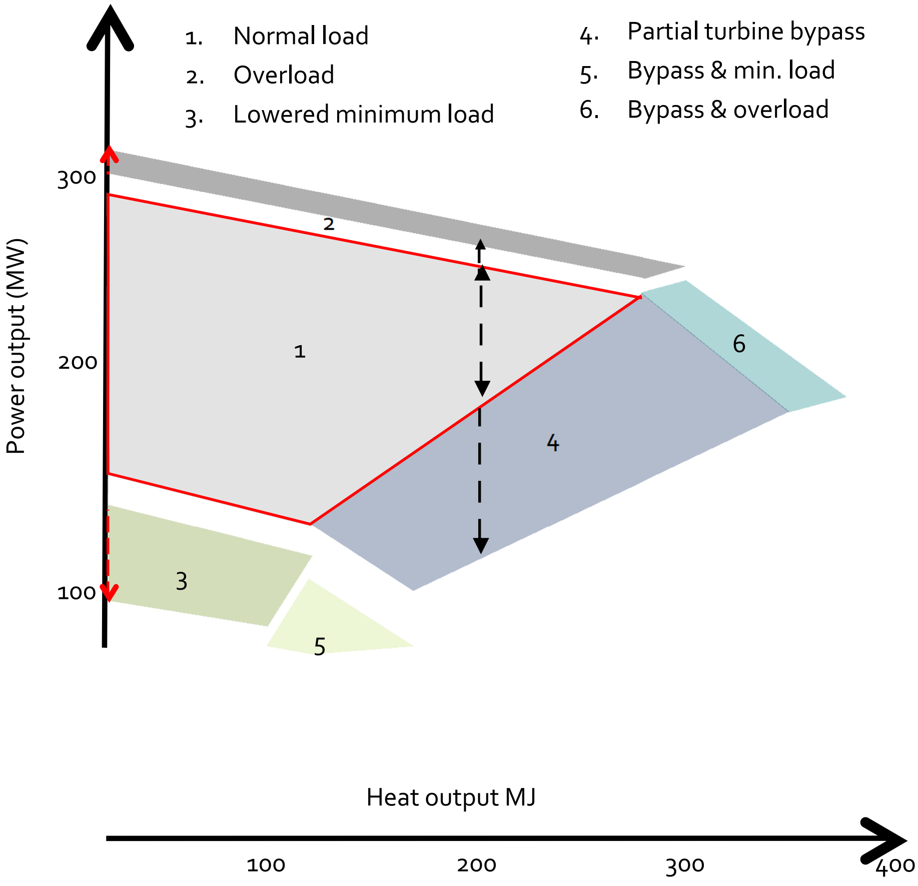
The changes and physical retrofitting that can be made on existing plants in order to enhance the operational flexibility are extremely varied in terms of complexity, investment need, effect, scope and the time they take to implement. Some enhanced flexibility can be unleased without physical retrofitting of the plant, but simply through changing the control system and operational practices as well as creating the appropriate incentives for providing more flexibility.

A simplified illustration of typical flexibility measures on a CHP plant and the effect such measures have on the possible production scope of the plant is illustrated in Figure . The figure illustrates a possible output envelope (power and heat) for a given 300 MW CHP plant - the grey area (area 1). The other areas (2-6) illustrate additional production output area that could become available through flexibility enhancements. The enhanced operational areas shown are conceptual illustrations and the specific effect of different flexibility initiatives depend on the specific plant.

For both condensing and CHP plants enhanced flexibility can be obtained through enabling the plant to operate in overload (area 2 for CHP plants) and by lowering the technical minimum load (area 3 for CHP plants).

For CHP plants the possible production area can also be expanded by investing the option to partially bypass the turbines (area 4) - or even fully bypass, which will enable the plant to deliver heat without power output at all. At a given heat demand (e.g. 200 MJ/s) the possible power output could be between 150 and 250 MW under normal circumstances, while the interval with partial turbine bypass instead could be between 75 and 250 MW (as in this illustration). In other words, the minimum forced power output at a given heat demand is reduced significantly by the option to partially bypass the turbines. The additional production areas 5 and 6 are enabled through the combination of partial turbine bypass (area 4) together with overload and minimum load enhancement initiatives.

Figure 19-1 Illustration of possible production area on CHP plant (operational envelope)



Aside from expanding the possible operational envelope of the plant as illustrated above, other flexibility measures aim for increased ramping speed of the plant, which allows the plant to change its output faster, and improved start/stop speed and reduction in the associated costs.

Enabling more flexible operation within the operational envelope of the plant through enhanced ramping and start/stop speed are relevant for both condensing and CHP plants. Other measures are only relevant for CHP plants. One such measure is to establish heat storage tanks, which typical can store enough district heat for the next 6-10 hours during peak winter season (or a weekend during warmer seasons). It is simple and relative cheap to store heat and the energy loss is low. It is an option which can be deployed with both large and small-scale CHP. Such a measure provides flexibility to the CHP plant by decoupling the normally relatively fixed relationship between heat and power output. Basically, it allows the plant to either reduce or increase power output and still deliver the exact required district heating by extracting heat from the heat storage tank, and loading the storage, when heat production exceeds consumption. This measure is particularly valuable for CHP plants which during peak winter periods are forced to operate at almost peak heat output. Finally, the investment in electric boilers or heat pumps can be an option that adds flexibility as both measures consume – instead of produce - power to supply district heating. However, the conversion from power to heat in electric boilers is – from an energy perspective – not an efficient solution. The add-on of smaller electric boilers can, however, be a fast-implementable measure to handle the most extreme peak imbalanced (providing down-regulation to the system) or to alleviate VRE curtailment.

Overview of flexibility measures

Table summarises the different flexibility measures presented above. Due to heat production on CHP plants specific measure pertain only to such plants - just as the different measures have different effects. Some measures expand the generation envelope, while other allows for a more flexible operation within the envelope. Some measures require technical retrofitting or add-ons to the existing plants, while others can be realised without hardware modifications.

Table 19-1 Summary of different flexibility measures

	CHP units	Condensing units
Expanding output area	-Overload ability	-Overload ability
	-Lowering minimum load	-Lowering minimum load
	-Turbine bypass	
More flexible operation mode within output area	-Improving ramping speed	-Improving ramping speed
	-Faster start/stop of plant	-Faster start/stop of plant
	-Heat storage tank	
	-Electric boiler, heat pumps, heat-only boiler	

Further to the specific flexibility measures on a thermal power plant as outlined above, considerations should also be made to the inherent difference in flexibility between one 1,000 MW unit compared to e.g. two 500 MW units in the situation where new units are to be added to the system.

The Danish experiences on the development of enhanced flexibility

Denmark has extensive district heating provided by thermal CHP plants and an increasing share of wind power covering around 40 % of total power consumption, increasing towards 50 % in 2020. The development of thermal power plant flexibly in Denmark has taken place over more than two decades continuously responding to the increasing need for more flexibility in the power market.

The first strong incentive pushing the development of enhanced power plant flexibility in Denmark was the liberalisation of the power market in 1999 and the increased competition from production with lower marginal cost from abroad. The power market provided clear price signals to all the market participants and in periods with high demand for district heating the CHP plants were not able to operate flexible, which created low market prices and losses for the power producers. As a consequence, the producers invested in heat storage tanks on all large and most small CHP plants in Denmark. The small CHP producers where initially incentivised for these investments by a time varying generation tariff, prior to entering the liberalised market alongside the larger units.

In the decade (2000-2010) that followed the liberalisation of the power market the share of variable renewable energy in Danish power consumption rose from around 10 % to around 20 %. The thermal power plants produced less, and the market had extended periods with low power prices. This incentivised the power plant owners to improve minimum load capabilities, enhance the ramping speed and further improve the decoupling of heat and power production. Consequently, the thermal producers became better equipped to supply fast production response to the Transmission System Operator (TSO) and thus tap into a higher value market delivering fast reserves. The increasing share of wind power also forced the power plants' owners to reduce operating costs and increase efficiently overall. This was achieved by implementing performance monitoring systems enabling optimised daily operation just as key performance indicators (KPI) were introduced to benchmark the performance of the individual power plants against each other. The optimisation that took place in this period was mainly involved limited investments in new hardware and the main costs were related to the engineering costs associated with operating more flexibly.

> Danish experience has shown that a high degree of thermal power plant flexibility can be obtained at relatively limited investment costs – particularly in the early stages of enhancing the power plant fleet.

Thermal power plant flexibility is a proven and important component in Denmark’s ability to integrate large shares for variable renewable energy in the power system.

Since 2010 the share of variable renewable energy (wind and solar power) in Denmark has risen from around 20 % to around 40 % of power consumption. Consequently, condensing units are no longer economically viable. Only CHP plants, which have much higher total energy efficiency due to combined heat and power production, are able to maintain profitability. Meanwhile, the CHP plants have had decreasing utilisation. They have adapted by becoming even more flexible by investing in more profound flexibility measures, continuing to enhance efficiency and decreased maintenance costs. It was not until this stage investment in enhanced flexibility required larger investments in new plant equipment and extensive hardware retrofitting. Due to more frequent and longer periods with low power prices increased focus was given to improving the start/stop time and associated costs[vii].

A competitive short-term wholesale power market with clear price signals will enable the thermal power plant sector to make the most cost and energy efficient investment in flexibility.

The specific development of enhanced flexibility and cost reduction initiatives in Denmark generally reflects a cost-efficient path. It is the existence of an efficient power market with clear and dynamic price signals that enables the thermal power plant owners to make the most cost-efficient investment and adjustments. Absence of a transparent price and a short-term wholesale power market with sufficient liquidity the power plant owners would only have limited – if any - incentives or information to make the adjustments and investments necessary for a cost and energy efficient power market development. The curtailment of variable renewable energy in Denmark has been close to zero even with the recent very high level of variable renewable energy in the system.

The German experiences on the development of enhanced flexibility

The share of the variable renewable energy in Germany (mainly solar and wind power) has risen from roughly 1.6% in 2000 to 19.4% of total power consumption in 2016. National energy policy aims to increase the share to 30 to 32% by 2020 to 52.7% by 2030.[viii] Although today’s share of these variable technologies is just 20 % of total power generation Germany experiences shorter periods with more than 70 % or even 80 % variable renewable electricity supply. Hence the flexibility challenge is already very acute in Germany today. A power system with more variable residual load needs to adapt and become more flexible. Retrofitting the existing coal power plant is one of the key sources in Germany.

The increasing share of renewable energy in Germany in the past years – in combination with low fuel and emission costs as well as a surplus of production capacity – has pressured the profitability of the thermal assets. Especially after the 2008 financial crisis the power price declined steadily due to drop of coal and gas prices and merit-order effect of high levels of renewables[ix]. Several power stations were forced to shut down due to insufficient revenue from low utilization[x] and the installation of heat storage systems, electric heat rods and back up boilers has been made to adapt to the increased need for flexibility. The upgrades and flexible operation of existing coal-fired power plants can contribute not only to the system reliability and stability as the share of variable renewable energy increases but is also a needed adaptation of the thermal power plant sector to the new normal economic landscape. Adequate economic incentives are the main driver ensuring upgrades and enhanced flexible operation. Economic incentives are the fundamental driver for the retrofitting of the existing power plants and the evolution of related technologies aiming to improve the performance of ramping, start-up time, minimum load and other flexibility improvements.

In examples of upgrades to improve the flexibility on some specific power plants in Germany is presented.[xi]

Table 19-2 German examples of upgrades to improve flexibility

	Measures	Change	Cost
Hard Coal Heilbronn Unit 7 800 MW	Switching from two to single mill operation	Reduction of minimum load down to 12.5%	n.a
Hard Coal Bexbach 721 MW	Switching from two to single mill operation	Reduction of minimum load down to 12.5%	25 million Euro
Lignite-fired power plant Jänschwalde 6*500 MW	Auxiliary firing with dried lignite ignition burner	The minimum load from 36% down to 26%	n.a

International experience - thermal power plant flexibility and investments

The existing data regarding large coal-fired power plant flexibility shows a relatively diverse picture. The reasons being variation in age, coal type and quality, plant configuration and component types as well as other factors influencing norms and best practice. A general assessment of the level of flexibility on thermal power plants in Denmark, China, and Germany respectively, is outlined below. This includes some of the different flexibility measures and indications of associated cost for improving the flexibility. Public available cost estimates are limited as power plant owners typical do not want to share such information, which add to the uncertainty about the level of investment costs required to improve flexibility.

Since the range of initiatives to optimise and retrofit thermal power plants for more flexible operation is so vast it is almost not meaningful to indicate level of investment costs on general level. Some initial improvements can be realized without any hardware retrofits or investment, but by solely focusing on changing the current operation mode of the plant.

This typically carries costs in form of increased operating costs. Other flexibility improvements require varied investment in retrofit and new hardware as well as software.

Minimum load

The experience from Denmark[119] is that the thermal power plants today typical have minimum boiler loads in the range of 15-30 %.[xii] For shorter periods and with the use of supporting fuels minimum boiler loads as low as 10 % has been reported. Typically the design minimum boiler load for Benson (once-through) boiler types is around 40-45 %, which can be reduced to the level of 20-25 % with generally modest retrofit investments[120]. When minimum boiler load is around 25 %, the efficiency will drop (perhaps as much as 10-12 %-point from peak efficiency) leading to even lower power output at minimum boiler level. A minimum boiler load of 25 % could therefore result in output dropping to 18-20 % of maximum output as result of reduced efficiency at low(est) boiler load.

Reducing the minimum load on a plant and using the new lower minimum load thus implies lower overall plant fuel efficiency. Viewed at plant level the cost and emissions per unit of output increases. However, if the overall system impact is positive – both in terms of total costs and emission – then the ability to reduce minimum load is attractive and should be promoted. One straight-forward example of how the overall system effect can be positive is if the reduced power output reduces curtailment of wind, solar or hydro power.

There are examples of plants from the USA that were retrofitted to operate at much lower load than original design values. Such examples point to the existence of plants capable of reducing output down to a level of approximately 20 % of nominated maximum output and even close to 10 % for several hours and with the use of supporting fuels.[xiii]

The current fleet of coal-fired power plants in China is in international perspective very new and preliminary high-level assessments suggest that the potential for enhancing the flexibility is very significant. Currently the typical minimum boiler load level in China is 50 %, but there are very recent examples of plants reaching boiler loads around 20-30 %.

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[119] Danish coal-fired power plants uses hard coal (i.e. there is not any significant use of lignite coal)

[120] Contrary to the Benson boiler the drum boiler (which has much lower efficiency) will usually have the ability to operate at 25 % load by default, but there might be a need for some adjustments – particular regarding the fuel handling system.

Table 19-3 Minimum boiler load comparison between China, Denmark and Germany

Minimum boiler load (hard coal)	China	Denmark	Germany
Typical level *	40-50 %	15-30 %	25-40 %
Best in class **	20-30 %	10-15 %	15-25 %

* For CHP plants in China minimum power *output* levels are typical higher (60-70%) during winter as the high heat demand forces the plants to deliver high power output.

** Only very few plants have reached 20-30% boiler load in China at present.

Reducing the minimum load in hard coal-fired power plants is typically constrained by many technical challenges that must be addressed. Some of the main challenges are enabling reduced fuel injection by adjusting the fuel feeding system, securing fire stability, maintaining adequate flame control, ignition, and avoiding unburned coal at low load. Further challenges that must be dealt with are lower and more volatile boiler temperatures and how that influences critical components as well as lower flue gas temperatures, which can make it difficult to maintain acceptable emission levels of NO_x and SO_2. To deal with such challenges investments are needed, but they depend on the specific plant's initial configuration and how low the minimum load is targeted.

Some of the needed investments to enable low load (i.e. in the range of around 20-25 %) potentially include indirect firing system, switching from two mills to single mill operation, refurbishment of the pulverizes, upgrade of control system in combination with plant staff upgrades, investment in flue gas recirculation system and not least a boiler water circulation system.

International and preliminary Chinese experience shows that minimum boiler load can be lowered from levels around 50% to around 25 % at relatively modest retrofitting investment costs.

The typical retrofit investment costs needed to enable a plant with a Benson boiler to go from around 40-45 % down to a minimum boiler load around 20-25% depends on the specific plant configuration and design. There will likely be a need for investing in a boiler water circulation system, probably investment needed in the fuel feeding system, control system updates and perhaps a need for investment in a flue gas recirculation system depending on the emission criteria. Such investments as these could be in the level of 15,000 EUR pr. MW (approximately 115.000 RMB pr. MW), which translates to a range in the size of 30-40 million RMB for a 300 MW plant (European cost estimates). This cost estimate is highly uncertain but indicates a rough level. For further reduction in minimum load higher investments must be expected.

Some recent cases from China points towards investment in the level of 10 million RMB per plant has been needed to reduce minimum load on 300 MW and 600 MW condensing plants from around 50 % to around 25-30%.

Overload

At times of generation scarcity, when up-regulation is needed, or it is simply cheaper to have plants running in overload instead of starting a new plant, most Danish power plants can operate in overload conditions. Generally, the overload enables to the plant to deliver around 5-10 % extra power output compared to a normal full load operation. If the plant does not have the necessary technical configuration already from commissioning then the typical needed investment costs associated with obtaining such overload ability is in the range of 1,000 EUR pr. MW nameplate capacity (European cost estimates), but again the specific investment might differ dependent on the given plant. Hence, for a 300 MW plant this translates into a rough price indication range of 2-2.5 million RMB.

Ramping speed

Danish coal-fired plants have shown examples of ramping speed in the level of 4-8% of nominal load per minute depending on the use of supplementary fuels like oil/gas to boost ramping (around 4 % on primary fuel and up to 8 % with supplementary fuels). The grid code requirements for coal-fired power plants are minimum 4 % of nominal load per minute (for power range 50-90%) and 2% for other power ranges. There is a large variation in the literature regarding the normal ramping speed capability of power plants. For new hard coal plants typical ramping speed of 3-4 % or even 6 % of nominal load pr. minute are mentioned, while older plants typical are expected to have ramping rates in the level of 1.5 % to 3-4 % of nominal load pr. minute[xiv]. In China the typical current level of ramping speed in existing Chinese power plants are in the level of 1-2 % of nominal load pr. minute.

In Germany the ramp rate of state-of-the-art coal power plants (hard coal and lignite) can reach 6 % of nominal load per minute. Even though the flexibility features of state-of-the art coal power plants are significantly better than those of older power plants it must be pointed out that coal-fired power plants are in general less flexible than gas-fired generation units regarding ramp rates.

Lignite-fired power plants in Germany with most commonly used technologies have the lowest average ramp rates 1–2 % of nameplate capacity per minute. But state-of-the-art lignite-fired power plants can ramp up faster as well, with an average ramp rate reaching 2–6 % of full load per minute (versus 1–2 % for most commonly used technologies) approaching the level of hard coal units.

The investment estimate for increased ramping speed depends very much on the required refurbishments. If changes are limited to software and reprogramming in the control-system, the cost is very low. However, if technical retrofitting is needed then costs will increase. The issue of reduced efficiency during ramping has been examined through experiments on existing Danish units and the average efficiency of the plant is not affected by ramping. However, the decreased lifetime of components that experience stress during the many reoccurring cycles is unavoidable.

Start-up time

Improving the start-up time and reducing the cost of doing so can also contribute to the overall flexibility capability of thermal power plants. The start-up time depends on whether the start is a hot, warm or cold start. A hot start is when a plant has been switched off within 8 hours of the next start-up, while the warm start is categorized by a plant that typical has been switched off between 8 and 48 hours. Finally, a cold start is a start when the plant has been shut down for more than 48 hours (i.e. perhaps after revision). The literature points towards that hot starts on hard coal-fired plants typical are between 1 and 5 hours, with the norm around 2-3 hours. State of the art hot start up times could be as low as around 1½ hours[xv]. The minimum criteria in the Danish grid codes require a hot start time of maximum 3 hours[121]. In China the typical current level of hot start times on Chinese plants are in the level of 3-5 hours.

Partial or full turbine bypass

Implementation of by-pass of the turbine at an existing coal-fired CHP plant is in general a rather complex and costly investment. However, different degrees of bypass have shown valuable to enable decoupling of heat and power production at CHP plants. As the share of variable renewable energy increases and the need and value of flexibility increases it might be worthwhile to let new plants be designed with partial or full bypass. A recent case example from Denmark is the decision to close an old coal-fired CHP plant and replace it with a new biomass based plant that can serve the same district heat market, but also is built with the ability to fully bypass the turbines and thus be able to operate as a heat only plant in times of ample power production from wind and solar.

Heat storage tanks

For CHP plants, large heat storage tanks designed to the specific size and profile of the local heating demand creates valuable flexibility to the power plant. Today all large CHP plants in Denmark and most of the smaller ones have installed heat storage tanks. Heat storage tanks enable the plant to continue to deliver the required heat demand (e.g. 300 MJ/s in a given period) while significantly change the power output (reduce or increase) depending on the need for thermal production at any given time. The heat storage tank simply functions as a "battery" for heat, which in effect decouples the normal fixed relationship between heat and power output. During the winter with high heat demand heat storage tanks are often designed to be able to cover all heat demand for a period of 2-6 hours, which create a valuable flexibility in times where demand for power output may

> Heat storage tanks are used extensively in Denmark to mitigate the effects of volatile power prices and are a key flexibility measure for CHP plants.

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[121] This time requirement of max 3 hours is for achieving synchronization with the net. For achieving full generation level the time limit is 5 hours.

vary very significantly. In the summer months such heat storage tanks are often able to deliver heat for hot water purposes during a whole weekend or more enabling the plant itself to shut down in this period. The size of the heat storage tanks depends on both the type of the tank, the scale and profile of local heat demand, the overall configuration of the power plant and the district heating system as well as the other flexibility measures of the plant. For the large power plants in Denmark (typical 300-600 MW nominal power capacity) sizes of the heat storage tanks typical range from 20,000 to 70,000 cubic meters (m^3) and investment cost in the range of 40-80 million RMB[122]. However, many smaller plants have heat storage tanks designed to their power and heat production output and are much smaller – but play an equal important role.

In Germany heat storages range from 20 MWh to 1,500 MWh and have storage volumes of 500 to 45,000 m3. The discharge duration of the different thermal energy storages varies by size and discharge capacity. For example, a large atmospheric thermal energy storage with a discharge capacity of 1,500 MWh and a water volume of 30,000 m3 has a discharge duration of about six hours reflecting the district heating market size of this particular plant[xvi]. This means that the power plant can in principle stop generation for up to six hours while providing a constant heat of 250 MW to its consumers through the discharge of its thermal storage.

Typical challenges and extra operation costs from flexible operation

Operating a power plant in a more flexible manner introduces some challenges in different forms. Some of the key challenges that need to be addressed and considered are increased maintenance costs from increased tear and wear on equipment, reduced lifetime, reduced fuel efficiency, emission control, and operational challenges and risks.

When operating at low load and when performing several large changes in load every day the wear and tear on the plant increases, which will decrease the lifetime of some of the plant components and increase the running operational maintenance on the plant. Experience has shown that this challenge is generally manageable and acceptable as the full load hours of thermal power plants are typically also reduced when the share of variable renewable energy increases, and more flexible thermal power plant operation is needed. As load is lowered then efficiency will inevitable also decrease leading to higher emissions per unit of output, which is must be taken into consideration. The efficiency will typical drop around 10-12 %-point from full load to minimum load (assuming around 25 % boiler load). However, when running at very low load, the purpose is often to reduce power output as much as

> There are certain challenges and additional operation cost associated with enhanced flexibility operation, but experience has shown these are manageable and acceptable in the light of the value from the additional flexibility.

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[122] The cost estimates are based on investment in heat storage tanks in Denmarkapp 15 years ago inflated to today’ s prices using average inflation index and converted from Euro to RMB at an exchange rate of 7.8. https://stateofgreen.com/files/download/290

possible and then reduced efficiency accelerates the reduction in output. When operating at low load keeping emissions at low levels can be challenged. However, experience has shown that Danish plants are able to comply with current emission limits despite running at both very low load and performing full load most days.

19.3 Incentivising thermal power flexibility investment and operation

Without economic incentives power plants owners will not be very motivated to invest in enhanced flexibility of their power plants – nor operate in a more flexible manner. It is the economic incentives present in competitive short-term wholesale power markets that have been, and still continues to be, the main driver behind investment in thermal power plant flexibility in Denmark, Germany, and elsewhere.

In the situation of limited economic incentives among the power plant owners an alternative option is to regulate or make direct requirements on the sector's flexibility capabilities. However, such approach might likely not result in cost-efficient solutions. A continued review of the current grid codes stipulating minimum flexibility criteria for new (and existing) units is a useful and valuable way to ensure that a minimum level of flexibility is secured. However, price signals from the power markets will likely lead to further flexibility enhancement investment and thus optimal level of flexibility among the thermal power producers.

Top-down approaches - even if differentiated in smaller geographic areas and differentiated by types of units etc. – will likely be too simple in their requirement and lack the insight of the power plant owners' knowledge about their plants and their market situation. Top-down approach will lack the full insight of each of the plants' individual technical flexibility situation, possible local district heating demand as well as the power plant owners' requirement on its return on investments and other company or plant related information needed for choosing the optimal and cost-efficient solution for the power system.

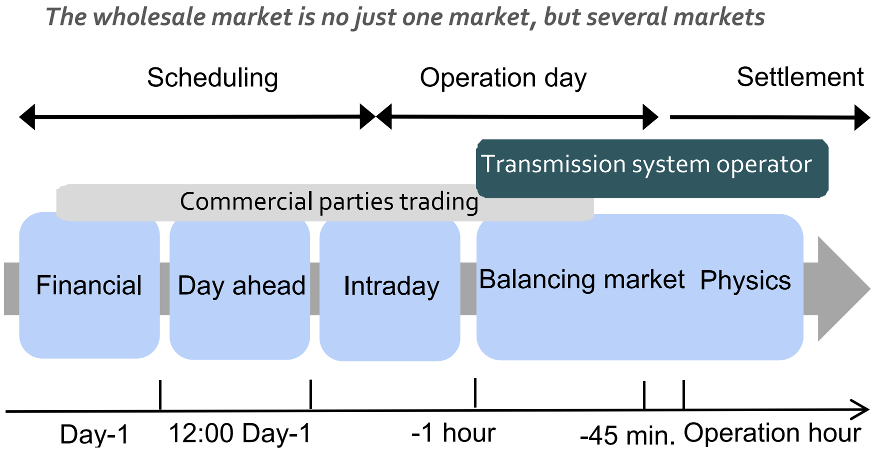
A cost-efficient way to incentivise more flexible thermal power plants is to develop short term wholesale markets. Here transparent price signals will give the power plant owners information about the value of flexibility and thus give them incentives to make demand-driven and cost-efficient investments suited for their plant and the local market situation.

Consequently, the optimal way to motivate enhanced power plant flexibility is to create clear market-based economic incentives and let the power plant owners decide themselves, which flexibility enhancement that is most cost-efficient or profitable for them to make. A successful and proven way to create clear economic incentives is to design a short-term wholesale power market where the demand and supply in the market generates transparent and reliable prices that signals what type and how much flexibility that is needed in the system.

Such short-term wholesale power market should naturally not cater for flexibility from thermal power plants per se, but rather incentivise the cheapest marginal sources of generation to be prioritized in the dispatch - as well as having the cheapest sources of flexibility being offered to the market irrespectively if the source is generation-side flexibility delivered from thermal power plants, hydro units, flexibility from demand response or storage etc.

As previously outlined in chapter 19 both Europe and elsewhere short-term wholesale power market is generally defined by several distinct, but interrelated markets where the market participants (wholesale producers and consumers as well as the overall balancing responsible (TSO and/or DSO) trade power and balancing products. In the Nordpool (Nordic) power exchange market trade take place in the period from around 36 hours before consumption up to around 15-45 minutes before consumption. An overview of these distinct, but interrelated markets is illustrated below for the Nordic region.

Figure 19-2 Overview of distinct, but interrelated power markets in the Nordpool market



One of the key characteristics of the above illustrated power market design is that the power plants' dispatch is not decided by a central dispatch organization deciding when and how much the different units should produce.

It is rather the market mechanisms that secure the balance between demand and supply by letting the wholesale producers and consumers react to the need and thus market prices for regulation and balancing in the market through the Day Ahead and Intraday markets. Once the Intraday market is closed, the system operator will take necessary action to ensure a balanced system by procuring short-term balancing products covering fast regulation.

The procurement of balancing products can either be based on a capacity payment for reserving capacity to be available for the system operator to call upon if needed to balance the system - or a payment solely for the regulation activated by the system operator.

Alternatively, a combination of both a capacity payment and a payment for the regulation activation is possible. The objective is to minimise overall balancing costs and the optimal design will thus depend on a multitude of factors where - for example - the dominant type of assets (e.g. gas turbines, large coal units, hydro, industrial demand response etc.) that can provide the flexibility will have influence.

The higher demand for flexibility there is (both Day-Ahead and Intraday market etc.) the higher the price volatility generally will be. This will incentivise the market to offer more flexibility. By observing these price signals in the market – and the expectation about how they will be in the future - the power plants owner (or other market participants) has the best possibly insight into the value of providing more flexibility to the system. This enables them to make informed decision about what investment in enhanced flexibility that is most valuable for them to make. Those who can deliver the regulation and balancing the cheapest will be the first to deliver to needs of the market. In this way the market mechanism ensures a high degree of overall cost-efficiency as the need for flexibility is provided by the cheapest source.

This is true for both for the Day-ahead market, the Intra-day market and the balancing market, which are the three main short-term markets in the Nordic power market (Nordpool). The market price in each of these short-term markets is a main factor in the decisions about what investments in enhanced flexibility that is profitable to make. Each market however incentivises flexibility in different ways as outlined in the table 19-4.

Table 19-4 Each market incentivises thermal flexibility differently

Nordpool	Market open/close	Value of flexibility in the short-term wholesale market
Day Ahead market	Opens 36 hours before and closes 12 hours before the first hour of operation for the next 24-hour period.	Avoid or minimise production when power prices are lower than marginal cost of producing to avoid/minimize losses from supplying
		Offer extra production to the market that can be delivered at high price situations
		Minimise imbalance (difference between sold and delivered amount) when moving from one hour or delivery to the next through fast ramping or start/stop
Intraday market	Opens at 2 pm the day before operation and closes 1 hour before each hour of operation	Offer up-regulation for the commercial market participants to procure
		Offer down-regulation for the commercial market participants to procure
	Offers are given up to 45 min.	Offer up-regulation for the TSO to procure

Balancing market[123]	before operational hour (activated 15-30 minutes before operation)	Offer down-regulation for the TSO to procure

The amounts and power prices the producer offer to the market is always decided to maximise its profits. The hourly changes of the market price create a very clear economic incentive for the thermal power producers to be very flexible in their production as outlined in the table 19-4. The future expectation about the level and volatility of the power prices are thus a decisive factor for what investments in flexibility that are optimal to make. It is therefore paramount that the power plant owners have confidence in the reliability and longevity of the power market structure and mechanism including the price formation setting to make the right investment decisions in enhanced flexibility.

Regulated price floors and price caps are often included in Day Ahead market design to avoid very extreme prices in situation of extreme supply scarcity or oversupply. This can give some comfort to the consumers, but it is paramount not to design a market with a too narrow spread between a price cap and floor. If the allowed price spread is too narrow the whole point of establishing the market is at risk of being diluted. Widening the allowed maximum and minimum prices ensure a more complete or accurate price signal is sent to the market participants in situations when the need for peak regulation is at its highest. By doing so a clearer incentive is provided to deliver flexibility when needed, which should incentivise investments in appropriate initiatives that can deliver the needed regulation and flexibility.

An illustration from a German dispatch model

The figure 19-3 below illustrates a modelling of two German coal power plants with different flexibility characteristics, but same efficiency standards [xvii]. The solid line represents a coal power plant without retrofit and limited flexibility. The dashed line represents a coal power plant with retrofit and improved flexibility characteristics, namely faster ramp-rates, faster start-up and lower minimum load. Because of high shares of variable renewable generation, the power plants in this modelled example are facing periods of low and even negative power prices in the Day Ahead market. Under sufficient long periods of very low or negative power prices the plants' profit maximising strategy would be to stop generating completely. When the price rises beyond the marginal costs the flexible plant can ramp up quicker than before and reach full load faster. From the system perspective, the reduction of fossil fuel use (substituted by lower operating cost of renewables) also implies the saving of total system cost.

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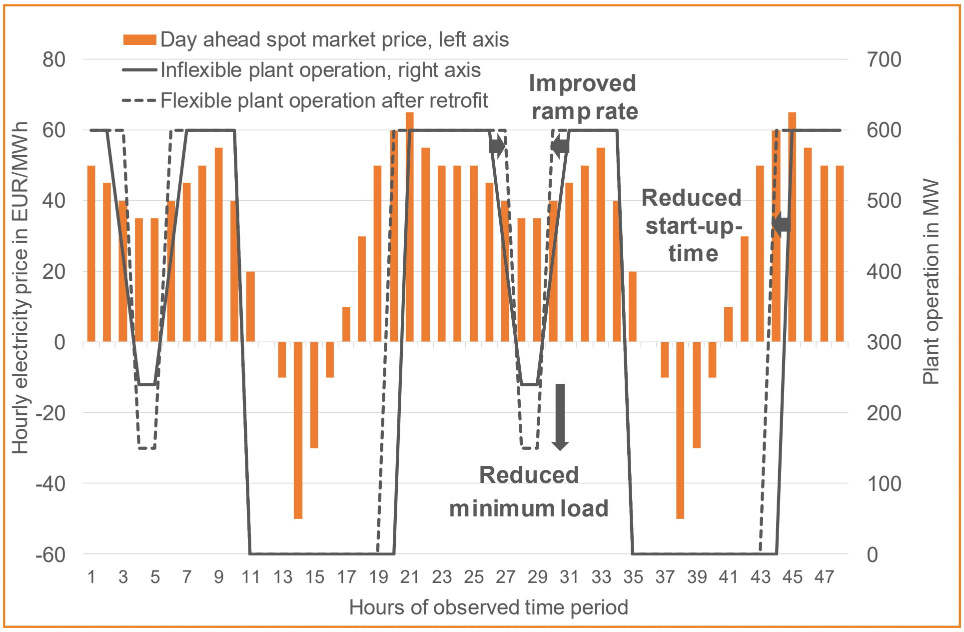
[123] The balancing market as presented here reflects the slowest form of balancing product in the Nordpool (the NOIS market), which in ENTSO-E terminology translate to m-Frequency Restoration Reserves or Replacement Reserves.

Once key source of improved earning is the improved ability to avoid operating at negative marginal contribution margins by either shutting down fully or lowering the power output to a minimum. In the case of fully shutting down the unit expensive shut-down and start-up cost must be factored into the decision. The trade-off between avoiding losses in hours with low prices and the cost of shut-down and start-up is pointing to a more beneficial operation mode with lowered minimum load and increased ramp-rates compared to fully shutting down the unit. But the optimal decision depends on the plant characteristic and power price levels and volatility.

Figure 19-3 Illustration of two modelled German plants with different flexibility characteristics



Differences in operation profit between a flexible and inflexible plant

A flexible thermal power plant can be more profitable than a similar less flexible thermal power plant in a competitive market based wholesale market like the Nordic because it provides (or restrains from) production and regulation at times where the system values it more and thus pays higher prices.

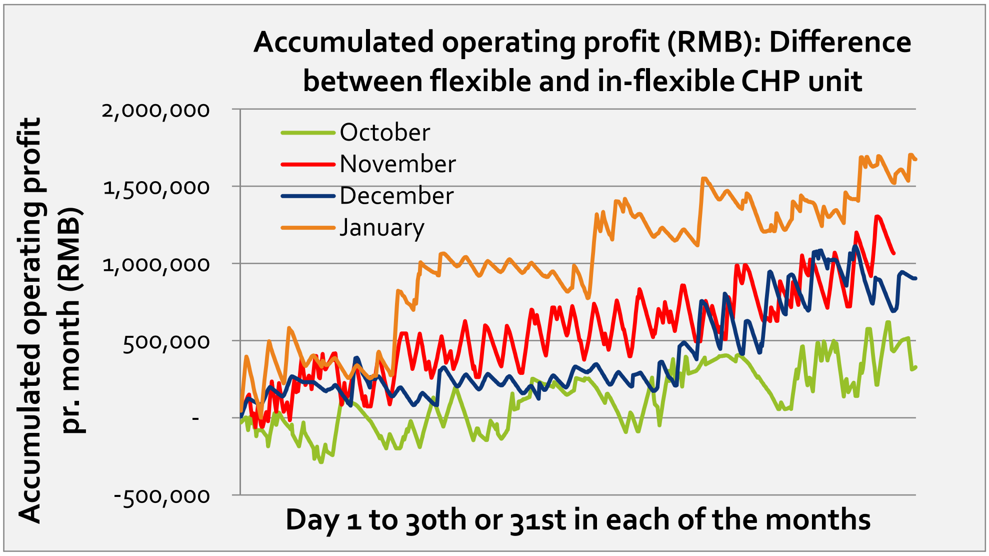
So how much higher operation profits can a "flexible" thermal power plant make compared to a similar, but just less flexible plant? It will make a higher profit, but the magnitude of this additional profit depends how valuable its flexibility is for the market.

Different flexibility measures provide different type of flexibility capabilities. The power plant owner will choose to enhance the plant's flexibility towards what the market values the most compared against the cost of supplying it. It is this interplay between market and plant owner that makes the market a cost-efficient method to incentivise enhanced thermal flexibility (and other sources of flexibility like demand responds and market coupling etc.).

A modelled case of enhanced flexibility in the Nordpool Day Ahead market

Using a software model two realistic, but fictional CHP plants were simulated to optimise their profits through operation in the Day-Ahead market. One of the plants was enhanced with a heat storage tank and partial bypass (the flexible plant). In all other aspects, the plants were completely similar and had the same district heating market size and heat demand profile. The difference in accumulated operating profit between the two plants is show in the figure 19-4for each of the first 4 months in the winter period.

Figure 19-4 Accumulated operating profit (RMB) difference between a modelled flexible and in-flexible CHP unit for 4 winters months.



Three key characteristics are clear when studying the figure 19-4:

- The accumulating operation profit from the flexible plant is generally higher each month than the inflexible plant.
- There is rather large difference between each of the months reflecting the difference in power and heat market between the months.
- There are shorter periods where the flexible plant earns less, which is caused by filling of heat content in the heat storage tank for later use. So basically, an investment in heated water that is stored in the tank for use in the coming days.

In this modelled case the difference in operating profit between the inflexible and the flexible CHP unit for one winter season was approximately 5 million RMB. This improved operational profit allows for a return on investments in enhanced thermal power plant flexibility and thus is the key driver for investment in enhanced flexibility.

Economic value of enhanced flexibility

The economic value a plant gets from using enhanced power plant flexibility depends on several parameters. These include:

- The general level and especially the volatility of the power prices in the future reflecting the need for changing loads and regulation
- The plant's production capability (minimum and maximum heat and power output levels) and flexibility measures such as heat storage tank, partial/full bypass, electric boiler or heat pumps etc.
- The local heat demand (both heat load profile and size of heating market) and heat price
- The ability to have accurate short and long-term forecasts for both heat and power
- Structure and level of tariffs and taxes on both power production and consumption as well as on heat production
- Many other factors also influence both the plants' generally profitability, but also their optimal dispatch such as efficiency, emission levels or ancillary service deliveries/requirements etc.

To illustrate the impact of some of the above factors the same simulation was made, but with different assumptions about the day-ahead power prices and the minimum load of the flexible plant. If it was assumed that the flexible plant also had a lower minimum load than the inflexible plant then it will be able to reduce power production further during periods with low power prices. This additional flexibility from having a lower minimum load increased the difference in operational profits between the flexible and inflexible plant from approximately 5 to 7 million RMB.

Using an assumption about more volatile power prices (more high and low prices during the year) the flexible plant's operating profit was not only 5 million RMB higher than the inflexible plant, but rather 17 million RMB for one winter season. If the power prices in the market are more volatile the value of having enhanced production flexibility increases significantly. It is this difference in the plant's operation profit that should be large enough to give a satisfactorily return on the investment in enhanced flexibility.

Economic value from overall system perspective

The value presented above only represents the economic benefits from the power producer's point of view. From an overall power system perspective other economic gains will be obtained by having more flexible power plants. These gains are achieved if the power market design and mechanism ensure it is the most cost-efficient production (lowest possible direct production costs) that meets the demand. Such benefits are obvious if the enhanced thermal power plant flexibility e.g. contribute to lowering curtailment of zero marginal production costs assets like wind, solar and run-of-river hydro power.

Different flexibility measurements give different options and value

The optimal investment in enhanced flexibility measurements depends on the initial investment costs, but mainly on how much value that is expected to be gained from the enhanced flexibility.

For example, the value of a heat storage tank increases when the spot prices have big daily variations and the plant can go into very low load operation. On the other hand, the value of an electric boiler will increase as the number of hours with very low power prices increases. That is, an electrical boiler depends on sufficient low power prices for a sufficient number of hours to be feasible.

Therefore the optimal investment of flexibility always depends on the specific existing production capabilities of the given plant as well as the design and economic incentive in the power market.

Power market design and dispatch regulation implications

Designing power market mechanism and economic incentives should motivate the investment in most cost-efficient sources of flexibility. The experience from Denmark, where wind power today makes up 40 % of the power consumption, is that investment in enhanced flexibility has proven to be a cost-efficient source of flexibility.

When power prices are settled by the market a very clear and dynamic price signal is available to the power producers, which is fundamental for them to decide what flexibility enhancement is the most profitable to invest in.

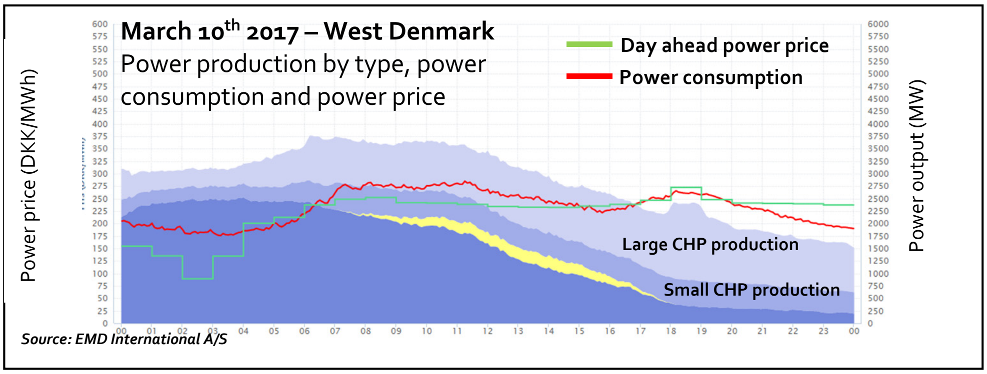
19.4 Illustration of power plant flexibility supporting VRE integration

With increasing shares of variable renewable energy, the need for power system flexibility increases. Each country, region or province have many different sources of flexibility supporting the overall power system balancing. Both Denmark and northern China have increasing amounts of wind and solar power in combination with CHP plants with corresponding forced power output following the local heat demand. If other sources of power system flexibility – like increased market coupling with neighbouring markets, fast regulating gas turbines or reservoir and pumped hydro power are limited highly flexible thermal power plant operation can be a key contributor to secure sufficient system flexibility.

In the case of Denmark highly flexible thermal power plants play an important role in the system's ability to integrate large shares of wind and solar power. In the figure 19-5,a 24-hour period is shown with the power production and consumption as well as power prices in the Day Ahead market from west Denmark (one price area).

During the 24-hour period the thermal production triples, reflecting the huge drop in the production from wind power. In the beginning of the period where wind power production surpasses the power consumption the power prices are being pushed downwards towards 0.012 EUR pr. KWh (app. 85 RMB pr. MWh). At such low power prices thermal power producers will lose money on their production. This creates extremely clear price signal for the thermal producers to not produce in these hours. On the contrary at the end of the period wind power production is almost none-existing and the thermal producers must deliver the most of the production. At this point in time the Day Ahead power price is close to 0.04 EUR pr. KWh, which will generate profits for the thermal producers.

Figure 19-5 One day's power production, consumption and power prices in the Day Ahead market in western Denmark.



Source: EMD International A/S

Utilities and power producers use long term power price forecast models to determine both price volatility and price level in the future as a key instrument to determine what type of investments to make. This includes decisions on which type of enhanced thermal power plant flexibility measure provides the best payoff for the producer. With the high share of variable renewable energy in the Danish power system, power prices have become more volatile and generally lower leading the thermal power plants to become very flexible.

Today, production from Danish wind parks and thermal power plants cover almost equal shares of the power consumption. In a few years from now the production from variable renewable energy will be the backbone of the production, while the thermal power plants increasingly will be the provider of flexibility to the system.

The situation is similar in Germany where the day-ahead market is hourly-based, and the price of power fluctuates significantly over the day. The conventional power plant, especially those fuelled by the hard coal must and do respond

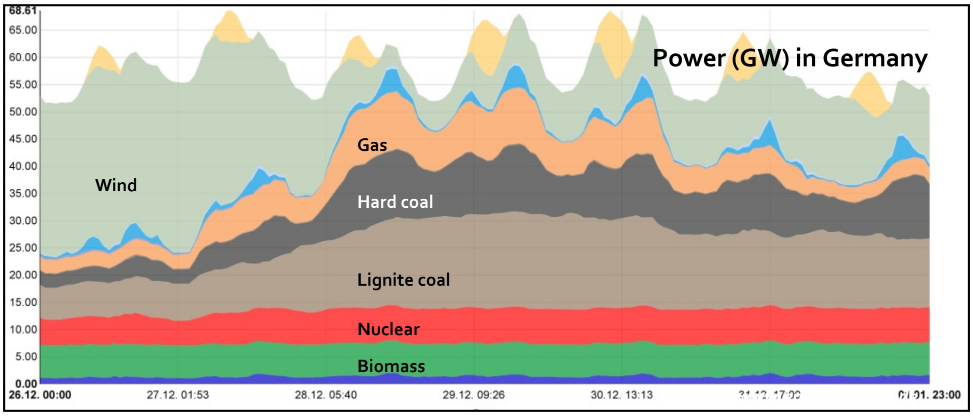
As the share of VRE increases a transition of the thermal power sector is inevitable. This transition will under a competitive market force the least efficient and least flexible plants out of the market and transform the thermal sector from being the production backbone of the system to be a provider of generation flexibility.

to the variation of the price i.e. reducing or stopping generation when price is low enough. Below is an example of production from one week in Germany during the 26th of December to the 1st of January 2017[124].

The power production during this period is in the range of 50-68 GW, but while the power generated from variable renewable energy (mainly wind) makes up around 50 % in the beginning of the period it drops to almost zero around the 28th of December.

During the period with high penetration of wind power the power price is generally between 0 and 175 RMB pr. MWh (not shown in the figure). At this point in time all coal (and gas) fired thermal power producers is strongly motivated to not produce as they would be incurring losses from producing. Even lignite fired power plants were also adjusting their output significantly during the period. After the wind power output is greatly reduced the power price increases to the level between 200-400 RMB pr. MWh.

Figure 19-6 German power production in the week 26th of December 2016 to 1st of January 2017.



If we only look at how much the hard coal-fired plants in Germany produces during the same period, we see in the figure 19-7 that the total output of the 49 hard coal fired power plants is only around 2 GW in the beginning and fluctuating significantly once the wind production starts to drop and eventually rise to around 12 GW. A significant part of the 2 GW is likely forced production due to district heating delivery – but such forced power production can be avoided using heat storage tanks, turbine bypass and electric boilers or heat pumps. We also observe a tripling of production (from 4 to 12 GW) in a rather short time – approximately 8 hours during the 28th of December.

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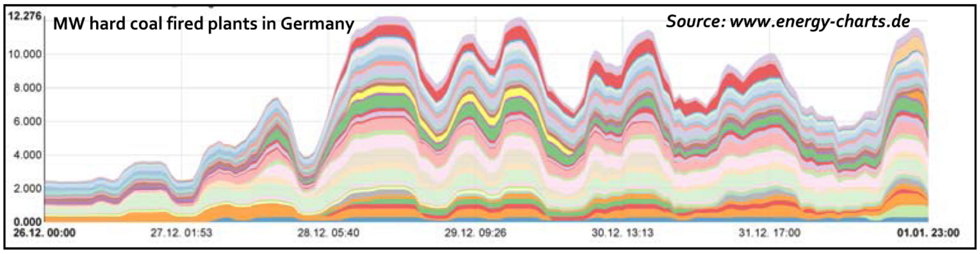
[124] Sources of data on German power production is from Fraunhofer (www.energy-charts.de)

Figure 19-7 Production from hard coal power plants (26th of December 2016 to 1st of January 2017)



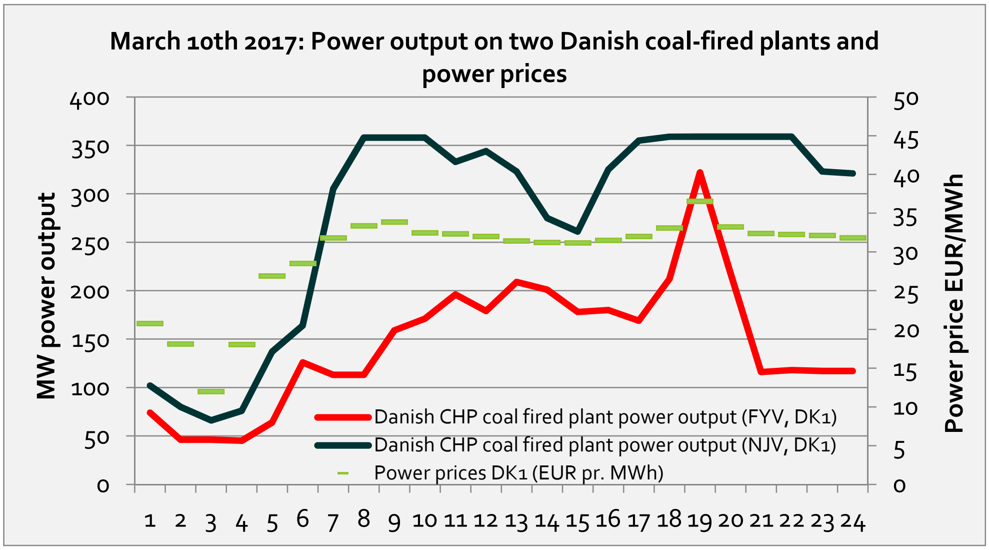
19.5 Plant cases: Flexibility of coal-fired plants in Denmark and Germany

The volatile day-ahead power prices that to a large extent reflect the level of VRE in the system, provides a strong incentive for the thermal power plant sector to adjust their production.

Figure shows the power output from two large coal-fired CHP plants in Denmark during the same period as in for the West Demark. When the day-ahead power price is at the lowest point during this 24-hour period (0.012 EUR pr. KWh) the two plants produce at their minimum output. In these two instances the power output is 50 MW and 70 MW while the maximum possible output on these units is 400 MW in pure condensing mode, but lower in CHP mode.[xviii] These examples show the ability of these units to reduce their power output to around respectively 12 % and 17 % of maximum output during this particular day. Both plants have installed large heat storage tanks, which provide additional flexibility during the winter season.

These are real life examples of how the power plants in Denmark react with great flexibility to the need of the market driven by the clear economic incentives provided by the day-ahead power market prices.

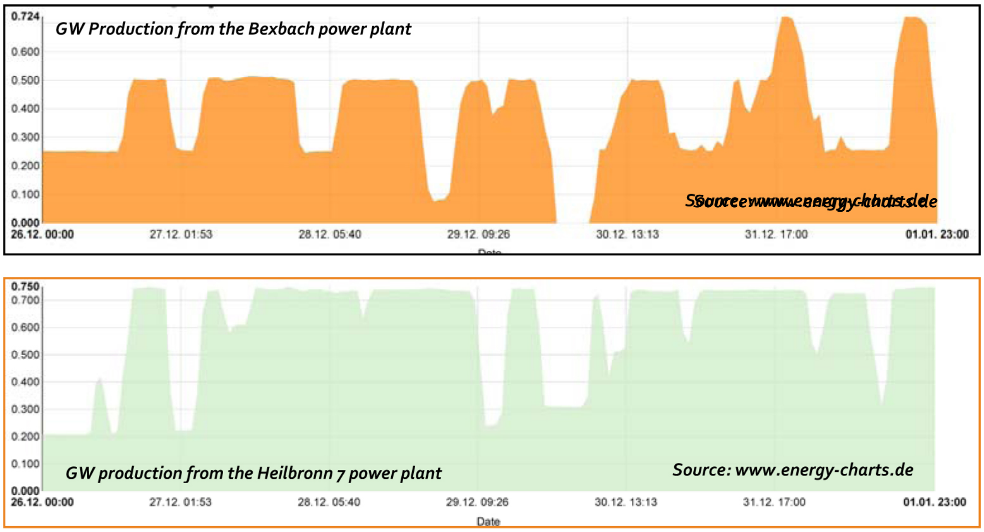
Figure 19-8 Power output for 24 hours from two large coal fired CHP plants and power prices



If we look at two (Bexbach power plant and Heilbronn 7 power plant) of the power plants mentioned earlier, which have been retrofitted to become more flexible we observe both plants operating very flexibly during the week from 26th of December to the 1st of January 2017. The fact that they are producing at all in the beginning of the period where the power prices are very low is likely because Bexbach power plant is the most efficient plant in the whole region it is located in and might be a must-run unit for balancing or reserve purposes while the Heilbronn 7 has a district heating market to serve which requires it to stay in operation at all times (given the lack of heat storage).[xix]

The examples given in the figure 19-9 are real-life examples of how the power plants in Germany react with great flexibility to the need of the market.

Figure19-9 Production from Bexbach and Heilbronn 7 power plant during the period 26th of December 2016 to 1st of January 2017.



19.6 Chinese system level analysis: Impact from enhanced flexibility

The role of power plant flexibility in the Chinese power system is studied using the EDO model. Certain power plant data is assumed for the EDO model to simulate investment in flexible new coal-fired CHP plants as well as investment in retrofitting existing both condensing and CHP plants to become more flexible[xx]. More specifically EDO has been set-up to simulate the outcome of four different flexibility measures described earlier in detail:

- Increasing maximum load (overload)
- Lower minimum load
- Partial bypass of the steam turbine
- Increased ramping speed of plant when in operation

The main types of coal-fired power plants used in the study of thermal flexibility are shown in the table 19-5.

Table 19-5 The main types of coal power plants relevant for the analysis of power plant flexibility

	CHP 350 MW		CHP 300 MW		Condensing 600 MW	
	New: Not flexible	New: Flexible	Existing (not flexible)	Retrofit (flexible)	Existing (not flexible)	Retrofit (flexible)
Maximum power (net) output at condensing mode (MW)	350	379	300	322	600	641
Minimum power (net) output at backpressure mode (MW) *	283	163	226	137	240	140
Maximum heating output (CHP only) (MW)	271	397	294	382	N.A.	N.A.
Ramping rate (% per minute)	2%	4%	1%	2-4%	1%	2-4%
Minimum net fuel input	40%	25%	40%	25%	40%	25%
App. investment cost for flexibility (1 Euro = 7.7 RMB 29th August 2017)	N.A.	+75 mill. RMB	N.A.	+ 125 mill. RMB**	N.A.	+82 mill. RMB**

* This is not the minimum power output in general, but minimum power output at maximum heat output.

** Included is 50% to cover for contingency and life time extension of some plants (see further description below)

Since retrofitting existing plants in the model is assumed to be a 15-year investment then the model assumes that plants that are retrofitted have a minimum of 15 years life time left. Since most of the retrofitting happens on the 300 MW CHP units already in 2020 and the Chinese power plant fleet is relative new this assumption seems reasonable. However, to take into consideration that some of the plants that are retrofitted in the model does not have 15-year left an extra average cost of 50 % are added on average for the retrofitting investment to cover the need for life time extension of some plants as well as to include some contingency regarding costs uncertainty for retrofitting existing plants (the 50% is a rough estimate made by CNREC and Danish Energy Agency).

The additionally investment cost for a 'flexible' new 350 MW CHP plant is assumed to be approximately 75 million RMB higher than the alternative ('no flexible') 350 MW CHP plant.

Included in in the additional price of 75 million RMB are all the four flexibility measures outlined above.

The investment cost for retrofitting (including all the four flexibility measures outlined above) for an existing 300 MW CHP plant is assumed to be approximately 125 million RMB, while the similar measure of enhancement of flexibility on the 600 MW condensing units is assumed to be 82 million RMB.

The model was only allowed to choose all the four measurements as a combined flexibility 'package' investment and therefore not able to choose just one or two of the specific measures mentioned above.

Scenario variations: ' No-flexibility'

Additional scenario variants were developed and compared with the two main scenarios (Below 2° C and Stated Policies). More specifically a scenario variant was developed for each of the two scenarios. The variants ('no-flexibility') does not allow for investment in retrofitting existing thermal power plant to become more flexibility or to invest in new more flexible power plants in contrast with the main scenario, which allow both options.

The alternative 'no-flexibility' scenarios were only modelled for 2020 and every 5 years until 2050. Consequently, in the rest of this section then the term 'Sum of the period' 2016-2030 or 2020-2030 only contains the sum of the respectively years (2016), 2020, 2025 and 2030. In other words, the sum for the period does not contain data for each of the years, but only the sum of every 5th year.

The main characteristics of all scenarios used in the analysis of this chapter are presented in Table .

However, under both the main scenarios as well as the 'no-flexibility' variations the model can invest in flexibility regarding the power-heat coupling in the form of investments in heat storage tanks, electric boilers and heat pumps.

Table 19-6 Scenarios used for the power plant flexibility analysis

Scenarios		Investments on new more flexible capacity	Investment in enhanced flexibility on existing plants (retrofit investment)
Main:	Below 2° C	YES	YES
Variant 1:	Below 2° C No-flexibility	NO	NO
Main:	Stated Policies	YES	YES
Variant 1:	Stated Policies: No-flexibility	NO	NO

Metrics for comparison of results

Increasing supply side flexibility can affect the Chinese power system in various ways. More specifically unlocking coal-fired power plant flexibility might:

- **Reduce overall system costs**. The costs of operating a power system can be split on capital (or CAPEX) and variable (or OPEX) costs. Retrofitting coal power plants can defer the need to invest in other costlier flexibility measures. Similarly running coal-power plants in a more flexible way can reduce system-wide operating costs by better facilitating penetration of solar and wind power and replacing more expensive flexible sources like natural gas units and oil-fired units.
- **Reduce coal consumption and increase VRE penetration**. Solar and wind resources have zero fuel costs and thus priority on dispatch excluding any technical constraints. Unlocking power plant flexibility can reduce the time over the year of getting technical constraints bidding in and causing VRE spillage; such constraints are occurrence of transmission congestion, unit related constraints like minimum/maximum generation constraints, ramping constraints and minimum up/down constraints and system wide constraints like spinning and non-spinning capacity reserve requirements
- **Affects the production of system-wide CO2 emissions**. Unlocking coal plant flexibility should preferable lead to reduced CO2 emissions due to increase on the share of solar and wind in the energy mix or from reduction of inefficient coal consumption. From an environmental point of view, CO2 reduction is the most important outcome as well. However, it is possible that any positive effect due to increased VRE penetration is offset by increased coal generation that replaces cleaner technologies like gas turbines or other effects in the energy system that have a negative effect on the total CO2 emissions. In power systems where flexible coal based power production is competing with flexible natural gas based power production appropriate CO2 pricing is likely needed for net reduction on CO2 emissions. In coal dominated power systems the effect on emissions depends also on the mode of operation of coal power plants prior to the flexibility interventions. If coal power plants were must-run a reduction on their minimum load will likely decrease their annual production and thus total emissions[125]. If, however, the power plants were not must-run flexibility measures might increase their operational time (Agora-Energiewende, 2017).

According to the previous discussion the analysis of the results focuses on the role of coal-power plant flexibility on:

1. Reducing system-wide costs
2. Decreased coal-fired power production and increased VRE production
3. Reducing system wide CO2 emissions

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[125] However, part-load operation of coal power plants increases a power plants specific emissions (kg-CO2/MWh)

Results of analysis: Cost impact

In the following focus will be on the short to midterm development meaning the development from 2016 to 2030. The majority of investments in flexible plants – either in the form of retrofitted or new flexible plants happens in the period until 2030 reflecting the role of enhanced thermal power plant flexibility as a tool to improve overall power system flexibility in the short to midterm in China. Most of the investments in flexibility are done in 2020 and to some extend 2025. Many other sources of system flexibility become available as time progresses including significant flexibility sources like high penetration of EV and minimum annual full load hour requirement is reduced linearly from the 2016 starting point to reach zero in 2025, and more and more regional coupling takes place during the 2020 and 2030'ies eventual leading to a national integrated market in 2040, as described in Chapter 8. At the same time retirement of coal-fired power plants happens as a response to the growing share of especially wind and PV power.

Total power system costs and average cost of electricity for the two main scenarios and the no-flexibility variants are calculated for the period 2016-2030. Costs are comprised of annualized generation capital and transmission capital costs, fuel costs, fixed and variable O&M costs and start-up costs.

The cost from emissions (particles, SO2 and NOx) and CO2-emission costs are not included.

The analysis shows that the main scenarios, which allows for investment in enhanced flexibility has a total power system costs for the period 2016-2030 that is lower than the no-flexibility scenario variations.

Allowing for investments in thermal power plant flexibility provide savings of 76 and 90 billion RMBs in the Stated Policies and Below 2° C scenarios respectively when comparing against the model variations where investment in enhanced flexibility is not possible. This translates to a total power system cost reduction of 0.8 % and 0.9 % respectively.

The lower total power system costs in the main scenarios arise mainly from savings on fuel costs and avoiding investments on new generation assets or avoiding more expensive sources of flexibility. Savings on capital costs can happen in three ways: a) by a lower need to add capacity into the system (through reducing min load and increasing max load) and b) by extending the life of existing assets and c) lower investment in other sources of flexibility that otherwise would be worthwhile. While there is savings from both capital costs and fuel & variable costs the fixed O&M costs are higher in the main scenarios.

The overall cost savings for both the Stated Policies and Below 2° C scenarios compared against the no-flexibility scenario variations are similar in both magnitude and type as shown in the table 19-7.

Table 19-7 Breakdown of total power system cost difference between the main scenarios and the no-flexibility variations for the period 2016-2030.

Difference between main scenario and no-flexibility scenario variants (2016-2030 billion RMB)		
Cost items *	Stated Polices	Below 2° C
Variable O&M	17	16
Start up costs	-5	-11
Fuel costs	61	61
Fixed O&M	-55	-56
Capital cost	58	80
Total cost	76	90
*Positive cost difference implies main scenario is lower cost than the no-flexibility variant		

If a CO2-emission cost of 50 RMB in 2020, 75 RMB in 2025 and 100 RMB in 2030 pr. ton is assumed then the cost difference between the Stated Policies and the Stated Policies no-flexibility scenario variant is increased 20 billion RMB for the period 2016-30 so total cost difference would be 96 billion RMB.

Given that the power production is different between the main scenarios and the no-flexibility variations it is relevant to also observe if the power system cost pr. MWh also is higher for the no-flexibility scenario variants. When comparing the two main scenarios with the two no-flexibility variants for the period 2016-2030 power system costs pr. MWh produced is respectively 1.4 RMB pr. MWh and 1.7 RMB pr. MWh higher in the Stated Policies and Below 2° C no-flexibility scenarios.

Results of analysis: Coal-fired power production and VRE production

Allowing for thermal power plant flexibility overall contributes to shifting coal-fired power generation to solar and wind under both the Stated Policies and the Below 2° C scenario.

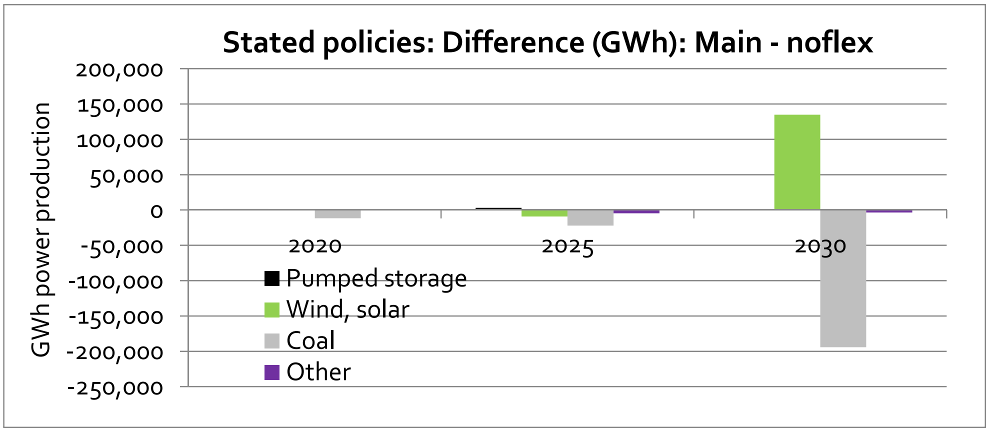
For the Stated Policies scenario coal-fired power production is however not reduced in 2020 and 2025, but in 2030 it is 5% lower when compared to the no-flexibility scenario variant. In 2020 and 2025 the combined production of wind and solar power is hardly effected, but in 2030 it is 4% higher when compared to the no-flexibility scenario variant. There are only very small changes in production from other technologies between the no-flexibility scenario and the main scenario in 2020, 2025 and 2030.

Table 19-8 Difference in power production between main scenario and the no-flexibility for the Stated Policies.

Stated policies: Difference in %: Main scenario compared to the no-flex scenario*	2020	2025	2030
Pumped storage	2%	3%	0%
Wind, solar	0%	-1%	4%
Coal	0%	0%	-5%
Other	0,0%	-0,2%	-0,2%
Total	-0,1%	-0,4%	-0,7%
*Positive numbers reflect higher production in the main scenario than in the no-flexibility variant.			

These differences translate to a reduction of coal-fired power production in 2030 of approximately 190,000 GWh and an increase of combined wind and solar power of approximately 135,000 GWh. In total the overall power production in 2030 in the main scenario compared to the no-flexibility scenario variant is 60,000 GWh lower.

Figure 19-10Difference in power production in GWh between the Stated policies scenario and the no-flexibility variant.



For the Below 2° C scenario relative similar effects are observed when comparing the main scenario with the no-flexibility scenario.

For the Below 2° C scenario coal-fired production is reduced respectively 0 %, 3 % and 4 % in 2020, 2025 and 2030 compared to the no-flexibility scenario variant. At the same time the combined production of wind and solar power is increased. The increase is negligible in 2020, but increases 2 % and then 1 % in 2025 and 2030.

Table 19-9 Difference in power production between the Below 2° C main scenario and the no-flexibility variant.

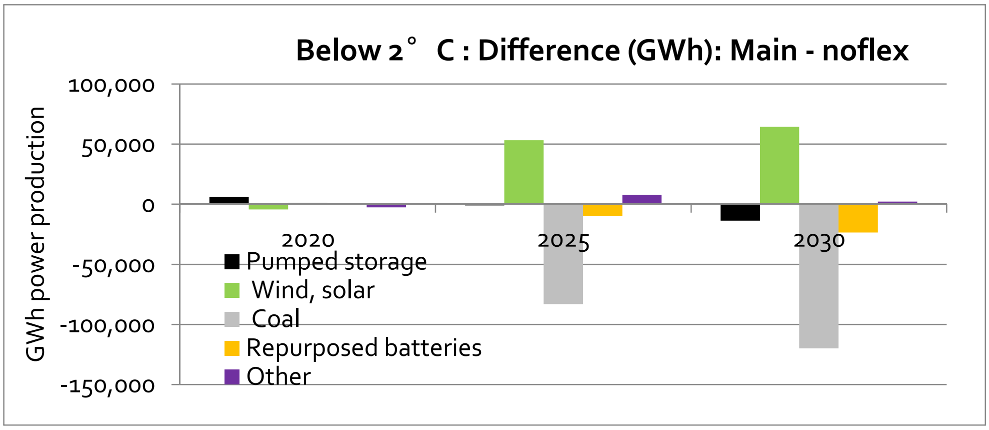
Below 2° C: Difference (%) : Main scenario compared to the no-flex scenario*	2020	2025	2030
Repurposed batteries	0%	-16%	-18%
Pumped storage	12%	-1%	-9%
Wind, solar	0%	2%	1%
Coal	0%	-3%	-4%
Other	0%	0%	0%
Total	0,0%	-0,4%	-0,9%

*Positive numbers reflect higher production in the main scenario than in the no-flexibility variant.

The differences translate to a reduction of coal-fired power production in 2030 of approximately 120,000 GWh and an increase of combined wind and solar power of approximately 65,000 GWh. In total the overall power production in 2030 in the main scenario compared to the no-flexibility scenario variant is 90,000 GWh lower.

Another noteworthy observation is also the difference in other generation side flexibility in the form of repurposed batteries and pumped storage. In 2025 and more pronounced in 2030 there is less output from both repurposed batteries and pumped storage in the main scenario where thermal power plant flexibility is available.

Figure 19-11 Difference in power production in GWh between the Below 2° C scenario and the no-flexibility variant.



Results of analysis: CO2 Emissions impact

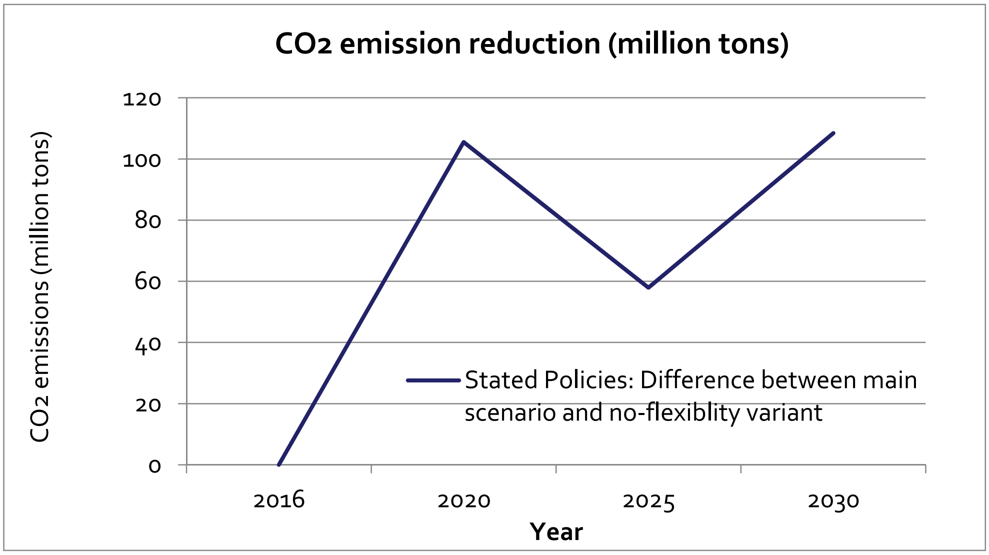
The figure 19-12 shows the total CO2-emission reduction from the power sector over the period 2016-2030 comparing the main scenario with the no-flexibility scenario. The CO2 emissions difference between the Stated Policies and Stated Policies no-flexibility scenarios is respectively -106, -58 and -108 million tons of CO2 for the years 2020, 2025 and 2030 meaning lower CO2 emission in the main scenario with thermal power plant flexibility.

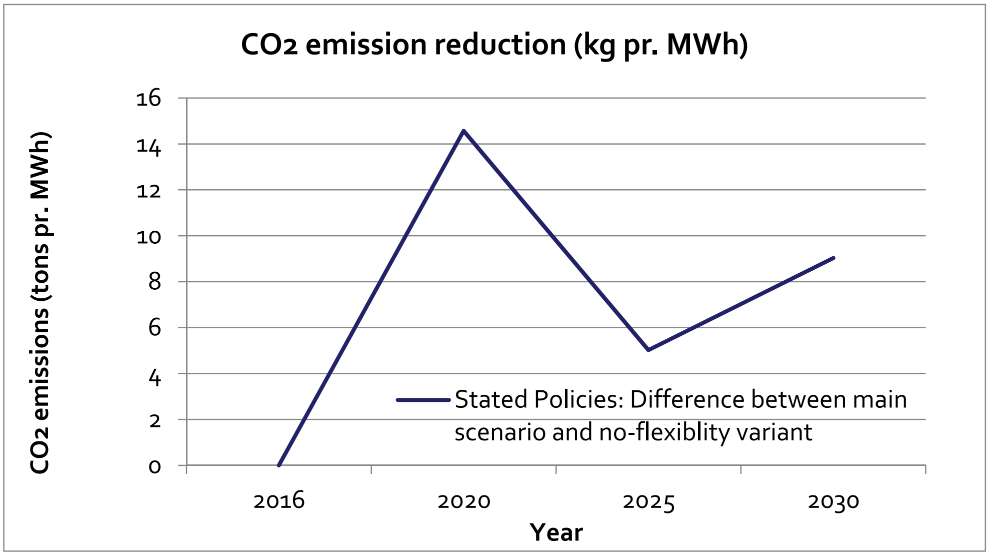
The yearly CO2 emissions saving for these years are roughly equivalent to 1.5-3 % of China's emissions from the power sector in 2016. This CO2 emission reduction follows the reduced coal consumption of approximately 1.5 % to 3 % in the period 2020-30.

Thus, the conclusion is that thermal power flexibility measures have a positive effect on the CO2 emissions in the Stated Policies scenario. If China continues with its current policies, adopting coal flexibility measures will bring a cumulative reduction in CO2 emissions.

In the Below 2° C scenario there is no difference in the CO2 emissions from the main scenario and the no-flexibility scenario. The reason is that in the Below 2° C scenario the model must keep emissions under the CO2 limit defined in Chapter 8, which is a criterion the model fulfils in the Below 2° C no-flexibility scenario by finding other – but more expensive - sources of flexibility.

Figure 19-12CO2 emission reduction from the power sector for the Stated Policies and Stated Policies no-flexibility scenarios in total and pr. MWh.





Results of analysis: Power system effects in details

When comparing the Stated Policies main scenario with the no-flexibility scenario in more details a more complex effect on the power system is observed (see also the table 19-20).

In short, the main effects are:

1) Coal-fired power production from condensing power plants is lower in the main scenario compared against the no-flexibility scenario variant.
2) Coal-fired power production from CHP plants is on the other hand much higher in the main scenario compared against the no-flexibility scenario variant.
3) Overall power production is lower in the main scenario compared against the no-flexibility scenario variant.
4) Coal-fired heat production from CHP plants is much higher in the main scenario, while heat from a heat-only coal-fired boiler is reduced significantly. Further, heat produced on electric boilers and particular heat pumps is also much lower in the main scenario when compared to the no-flexibility scenario variant.

The overall impact from allowing the model to invest in flexibility is thus a shift in production from respectively power-only (condensing) coal-fired plants and heat-only coal-fired boilers towards more combined heat-power production on flexible coal-fired CHP plants (see the figure 19-13).

Figure 19-13 Difference in heat and power (2020-2030) between Stated policies and no-flexibility.

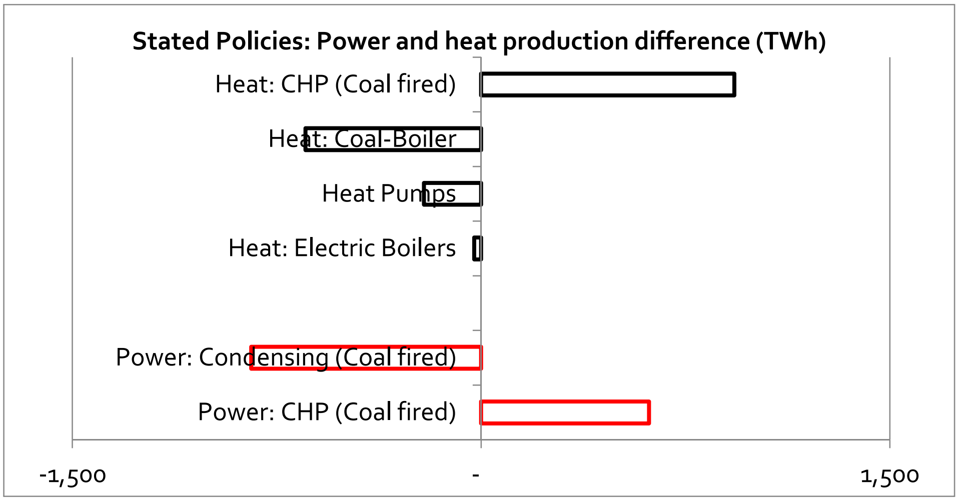


Table 19-20 Power, heat and CO2 emission differences between Stated policies and no-flexibility scenario variant.

Power production TWh / (% change from no-flex)	Stated Policies: Main - noflex		
	2020	2025	2030
CHP (Coal-fired)	104 / (8 %)	331 / (23 %)	180 / (11 %)
Condensing (Coal-fired)	-116 / (-4 %)	-354 / (-11 %)	-374 / (-15 %)
Sum	-12	-22	-194

Heat production TWh / (% change from no-flex)	Stated Policies: Main - noflex		
	2020	2025	2030
Electric Boilers	-9 / (-49 %)	-3 / (-27 %)	-14 / (-46 %)
Heat Pumps	-7 / (-39 %)	-73 / (-73 %)	-131 / (-60 %)
Coal-Boiler	-226 / (-37 %)	-267 / (-49 %)	-152 / (-39 %)
CHP (coal-fired)	249 / (27 %)	377 / (31 %)	302 / (20 %)
Sum	8	35	6

CO2 emission mill. Tons / (% change from no-flex)	Stated Policies: Main - noflex		
	2020	2025	2030
Coal-Boiler	-82 / (-37 %)	-97 / (-49 %)	-55 / (-39 %)
CHP (Coal-fired)	99 / (8 %)	332 / (25 %)	232 / (15 %)
Condensing (Coal-fired)	-122 / (-6 %)	-294 / (-12 %)	-286 / (-15 %)
Sum	-105	-59	-109

The main CO2 emission reduction in the main scenario compared to the no-flexibility is consequently a result of less coal-fired power production and a shift of heat from heat-only coal boiler, heat pumps and electric boilers - to heat produced on coal-fired CHP plants.

Results of analysis: Summary

The model results for both the Stated Policies and Below 2° C scenarios show that the system costs in general are reduced from thermal power plant flexibility when comparing against the no-flexibility scenario variations. This is true even without including the costs associated from higher level of emissions in the no-flexibility scenarios.

Having thermal power plant flexibility also reduces the coal based power production. The availability of thermal power plant flexibility means that the combined power production from wind and solar power generally increased. In the Stated Policies scenario a reduction of CO2 emissions in the level of 1.5-3 % is observed in the main scenario compared to the no-flexibility scenario variation. In the tables 19-21 the key findings are shown.

Table 19-21 Key differences between the main scenario and the no-flexibility scenario variations

Stated Policies: Difference in percent between main and no-flexibility scenario	2020	2025	2030
Total system cost*	1%	-3%	-1%
Total system cost per MWh*	1%	-2%	-1%
Coal based power production	0%	0%	-5%
Combined wind and solar power	0%	-1%	4%
Power sector CO2 emissions	-3%	-1%	-3%

* The cost does not include costs associated from higher harmful emissions in the no-flexibility scenarios

	2020	2025	2030

Below 2° C			
Total system cost*	1%	-2%	-1%
Total system cost pr MWh*	1%	-2%	-1%
Coal based power production	0%	-3%	-4%
Combined wind and solar power	0%	2%	1%
Power sector CO2 emissions	N.A.	N.A.	N.A.

* The cost does not include costs associated from higher harmful emissions in the no-flexibility scenarios

19.7 Key policy messages

Enhanced thermal power plant flexibility is internationally a proven and cost-efficient way of improving the power system flexibility and its ability to integrate increasing shares of VRE. The lesson learnt from Denmark and Germany is that the thermal power sector over time will move from being the backbone of the power production to become a provider of flexibility and consequently leave the main production for the VRE technologies.

Cost-efficient investment in enhanced thermal power plant flexibility can be incentivised by ensuring that the power market sends clear price signals to the market participants reflecting the value of particular types of flexibility needed at different times and situations. International experience shows that competitive Day-Ahead, Intraday and balancing markets provide economic incentives supporting enhanced flexibility in the thermal power plants. Reforms of power markets can ensure that market-based economic incentives are created to drive the development of a more flexible power system – where enhanced flexibility in the thermal power sector can contribute in the short run and in particular geographic areas with clear need for more flexibility.

Given the investment horizon in the power sector is relative long then investment decisions – including decisions to enhance the flexibility of power plants – will be done on the basis of the expectations about the future many years ahead. For this reason, it becomes very important that the power plant owners and other stakeholders have confidence in the reliability and longevity of the power market structure and mechanisms that are being introduced as part of market reforms. The more uncertainty there is about the market rules and pricing mechanism the higher return investors will demand for any investment, which will hamper the investments in enhanced flexibility. Hence, a clear roadmap and strategy for the development of short-term competitive power markets is instrumental to incentivize cost-efficient generation-side flexibility of which thermal power plants are one main source.

The results from the EDO model's two main scenarios show that enhanced thermal power plant flexibility can play a key role in improving China's power system flexibility and its ability to integrate increasing shares of VRE – particularly in areas with high curtailment levels. The result shows that a significant part of the existing CHP plants will be retrofitted in 2016-25 to become more flexible and most of the new CHP plants will be invested to be more flexible than the current level. The analysis also shows that it is only cost-effective to retrofit a limited share of condensing power plants. Enhanced flexibility at CHP power plants in China is a cost-efficient source of flexibility that can contribute in the short run to enhancing the overall power system flexibility.

Comparing the main scenarios with scenario variations where there is no option to invest in enhanced flexibility shows that the needed investments in thermal power plant flexibility is smaller than the overall system value it contributes to the system. Including costs from higher CO2 emission in the no-flexibility scenario variation only added to the cost difference between the main scenario and the no-flexibility scenario. Enhanced thermal power plant flexibility thus provides a net economic gain in China on system level.

Enhanced thermal power plant flexibility overall contributed to the system's ability to increase the share of VRE and lower the coal-fired power production. The results from the Stated Policies scenario show that the overall power system CO2 emissions are lower when investment in thermal power plant flexibility is made possible.

Overall the EDO model results point towards both positive cost and climate impact from enhancing the ability of power plant flexibility. On the basis of international experience and the model results the ongoing power market reforms in China must ensure economic incentives reflecting the value of flexibility is created so cost-efficient and appropriate investments in enhanced power plant flexibility is motivated. This should lead to reduced overall power system costs and enable a higher share of VRE and reduced CO2 emissions.

20 Distributed Renewable Energy

20.1 Status of Distributed Renewable Energy Development

Definition

Distributed energy is power supplied at the site of consumption, which can be either independently operated or grid-connected. With benefits as high efficiency, energy saving and environmental protection, nowadays, many developed countries have been able to improve the utilization efficiency of distributed energy to over 90%, which is much more than the efficiency of traditional energy consumption methods.

Distributed energy is a form of energy utilization that is different from centralized energy. There is no uniform global standard for the definition of distributed energy, however, the understanding of its characteristics is similar in various countries. The main characteristics of distributed energy include three aspects: first, the scale of the project is small, and the size of distributed power generation is between kilowatt-level and megawatt-level; second, the project is close to the energy load, and power generation is accessed at the power distribution network and the power generated is mainly for local consumption; third, in addition to power generation and heating-side technologies, the project includes a series of technologies for both sides of supply and demand.

Distributed energy mainly consists of two major technologies: 1) high-efficiency CCHP system with natural gas; 2) distributed renewable energy technologies, which can make distributed development and application of solar, wind, biomass and geothermal generation, to meet various final energy requirements such as power, heat, gas and transportation energy consumption.

Characteristics and Advantages

The characteristics and advantages of distributed energy are:

1) High efficiency of comprehensive energy utilization

With cogeneration of cooling, heat, and power, distributed energy can achieve the tiered utilization of energy, and the energy utilization efficiency can reach more than 80%.

2) Low energy transmission loss

Distributed energy is installed on the consumer side, which can provide energy nearby and doesn't need long-distance transmission, so the energy loss during transmission is greatly reduced.

3) Flexible operation of the energy system, which is conducive to high proportion development of renewable energy

Renewable energy power generation with wind or solar energy is subject to the resource intermittence and volatility, and the main network could be strongly impacted by large amount of distributed renewable generation; however, distributed power generation provides a new way for renewable energy integration.

4) Good performance in environmental protection

Application of distributed energy can effectively use decentralized renewable resources, such as solar, wind, biomass and geothermal, which can significantly reduce fossil energy consumption and air pollution emissions. Improvement of energy utilization efficiency and reduction of transmission loss are also beneficial to reducing environmental pollution. Abundant nearby power supply can reduce need for long-distance high voltage transmission lines, and reduce the corresponding electromagnetic pollution and environmental damage during the construction of power lines.

5) Solving the problem of energy supply in remote areas

As China is vast in territory and complex in geography and landform, many remote areas and rural areas are far from the bulk power grid, so it is difficult and expensive to supply energy using centralized method. The issue of energy access in remote areas can be effectively solved when distributed energy is developed according to local resource availability.

Distributed Renewable Energy Generation

Status of Technology Development

In China, commercialized distributed power generation technologies at present include natural gas power generation and renewable energy power generation. Except large-scale photovoltaic power stations and wind farms, most renewable energy technologies are distributed technologies, including distributed photovoltaic power generation, small-scale hydropower, small-scale wind power, biomass power generation and CHP. These technologies have different characteristics and are at different stages of development. The problems they are facing and the potential for market development are also different. In general, renewable energy power generation technologies are relatively mature; however, there is still room for improvement on cost and technology performance in the future.

Distributed PV power generation is a main form of photovoltaic generation applied in Europe, Japan, the United States and other countries and regions. Because most of the projects are installed on the facade of the buildings, it is also known as rooftop PV power generation system. Since the 12th Five-Year Plan, the Chinese government has strongly supported the development and application of distributed PV, and has introduced a series of policies and management measures. Therefore, the distributed PV will continue to be the major form of distributed renewable energy applications in the near future. There is still room for substantial cost reduction in these technologies. In 2016, the newly installed capacity of distributed PV power generation was 4.26 GW, with a total installed capacity of 10.32 GW.

Distributed biomass power generation mainly includes waste incineration power generation, landfill gas power generation, forest and agricultural biomass gasification power generation, and farm biogas power generation. Most of the biomass direct-fired power generation and biomass CHP generation units are connected to the medium- and high-voltage grid for unified dispatching, and they are usually managed under large-scale power stations. For distributed biomass power generation, waste incineration power generation and landfill gas power generation are most widely used, while forest and agricultural biomass gasification power generation and farm biogas power generation are less used. The main reason for the situation is that the project size of agricultural and forestry residue gasification power generation and farm biogas power generation is smaller and the gas production is not high, and the benefit of direct utilization as gas fuel is better than that of power generation. In 2016, the newly installed capacity of waste power generation and biogas power generation was 1.057 GW and 19 MW respectively, with cumulative installed capacity of 5.74 GW and 0.35 GW.

Distributed wind power. In Denmark, distributed wind power is the main form of wind power development. Many small-scale wind farms are constructed near villages and the consumers, and a project can be composed of one or several wind turbines. Since 2011, China has begun to promote the development of distributed wind power. However, due to various factors such as high cost of low speed wind turbine, site selection and land policy for projects and complex approval procedures, the development of distributed wind power has been slow. In 2017, the National Energy Administration issued documents again to promote construction of distributed wind power projects, requiring each province to develop distributed wind power development program for the 13th Five-Year Plan. It specifies that the scale of total distributed wind power projects is not limited by the annual capacity constraints issued in the national guidance, encourages the construction of distributed wind projects for self-generation and self-use, for balancing within the local micro grid. It further demands the grid companies to ensure grid connection of qualified distributed wind projects. At the same time, rapid breakthroughs have been achieved in low wind speed wind turbine technologies; with constant refreshing of the lowest wind speed for economic development (reduced from the past 6m/s to the current 5m/s), the wind resource threshold can be effectively lowered. With the technical improvements of the low wind speed turbine as well as simplification of the project management and the grid-connection management procedure, the distributed wind power will become an important new renewable energy market in the low wind speed regions of the central and southeast China.

As for small-scale hydropower, China has developed mature technologies and good economic efficiency. However, with higher development rate, the small-scale hydropower is currently limited by resource conditions and ecological environment constraints and its development potential of resources is limited.

Distributed Generation Regulatory Framework and Management Mechanisms

Renewable energy power generation is a mature technology. China has established a basic regulatory framework and management mechanisms for power generation and grid-connection of renewable power, and has set up a fixed feed-in tariff and charge compensation mechanism to support the renewable energy power. China has also carried out adjustments according to the development of various renewable energy technologies, in order to form a more comprehensive and effective tariff incentive mechanism for renewable energy. Fixed FIT has been issued already for many distributed renewable energy electricity by technology types, including PV generation, forest and agricultural biomass gasification power generation, urban waste power generation, biogas/gasification power generation. For distributed PV projects, quota-based subsidy has also been promulgated.

Distributed PV power generation projects are not limited by the annual capacity limit, and the project management is greatly simplified. Considering resource conditions, development basis, power grid consumption capacity and supporting basic measures, the National Energy Administration began to implement the annual guidance on capacity management for PV power generation in 2014, in order to determine the construction size of the new PV power station and to decompose the construction down to each province (autonomous region and municipality), so that the projects within the capacity limit can be eligible for the national renewable energy fund subsidies. The document clearly stipulates that, the construction scale of the roof-based distributed PV power generation projects as well as all the self-generation and utilization ground-based distributed PV power generation projects shall not be restricted. In 2016, the types of the distributed rooftop PV power generation projects without limits of construction limit is further refined, consist of only those using fixed building roofs, walls and ancillary sites. Moreover, the registration of distributed PV power generation projects has been greatly simplified, and supporting documents such as power generation operation permit, siting plan, land pre-trial, soil and water conservation, environmental impact assessment, energy conservation assessment and social risk assessment, have been exempted. For the distributed PV power generation projects constructed on individual-owned residence or within the residential areas, the local power grid enterprises shall aggregate them and directly register the projects and apply for registration to the local energy authorities.

The grid code and management system for distributed renewable power grid-connection are relatively sound. SGCC and CSG have issued corresponding management technical requirements for renewable energy power generation project grid-connection, to clear the definition of distributed power. The most widely used distributed PV grid-connection procedures have been greatly simplified. Since 2012, the State Grid has issued several documents and regulations, including the *Interim Measures on the Management of Distributed PV Projects* in 2012 and the *Regulations on the Management of Distributed Power Grid-connection Services* in 2014. The grid-connection procedure is simplified with specific timeline for completion: after receiving the grid-connection access application by the project company, the grid enterprise shall issue reviews of grid-connection within 20 working days; for the distributed PV power generation projects accessed to the power grid at voltage level of 35kV or below, the prefecture-level or county-level power grid enterprises shall, in accordance with the simplified procedures, process the relevant grid-connection procedures, open up the green channel, accelerate the speed of distributed power grid-connection, and provide high-quality service of ‘integrated services’ to the project owners. Multiple charges are exempted. The following services are free of any service charges: distributed power grid-connection application for acceptance, project registration, program development of access system, design review, power meter installation, signing of contract and agreement, grid-connection acceptance and commissioning, subsidy power measurement and subsidy fund settlement services.

The exploration of distributed power generation market trading is under way. In April 2017, the National Energy Administration issued a document to solicit opinions on the *Notice on Developing Pilot Marketization Trading of Distributed Power Generation*, and proposed to carry out the pilot market trading for distributed power generation. The basic ideas of distributed market trading are as followed: distributed power generation project companies shall conduct the power trading with the consumers within the distribution network; power grid enterprises shall bear the power transmission of distributed power generation and organize the public services of power trading, and charge the wheeling fee in accordance with the charging standards approved by government. Three modes can be selected for distributed projects: 1) direct energy trading with consumers, paying the wheeling fee to the power grid enterprises; 2) commissioning the power grid to sell the power (the price is equal to the total sales price of the power minus the wheeling fee); 3) full feed in tariff without participating in market trading (the price of power is equal to the sum of benchmark power price of coal-fired in local region and the 110kV transmission-distribution power price approved by the government). The charging standard for wheeling fee is also defined in the document: for self-generation and power consumers (including microgrid consumers), who consume the power at voltage level of 10kV (20kV) in the same substation area, the wheeling fee shall be exempted; for those who access the power grid at voltage level of 35kV to 110kV and consume the power in the same substation area, the wheeling fee shall be the highest transmission-distribution tariff approved by the government minus the transmission-distribution tariff of the voltage level in the local region where the power consumer is located. Under the overall framework of power market reform, the *Notice* has put forward market design and trading method that is targeted at the problems encountered during the development of distributed generation, and will lend a positive boost to the growth of the distributed renewable energy market.

Distributed Renewable Energy Heating

Status of Technology Development

Most renewable energy heating projects are distributed utilization, including solar energy heating, biomass heating, geothermal energy heating, and renewable energy power heating, to provide residential hot water, industrial hot water as well as heating and cooling for buildings. In recent years, the technologies and market of renewable energy heating have developed rapidly. Starting from small-scale system for households, more large-scale commercial application systems have been developed.

Solar energy heating: mainly heating by solar energy collector. The technology is mature. This method has been commercially applied on a large scale in the field of civil and industrial hot water, and has started in the field of building heating. Due to the large-scale market and good application conditions, it has been the main type of renewable energy heating in China.

Biomass energy heating: mainly refers to CHP and biomass boiler heating. It has been used in the fields of urban residents heating, industrial production heating and so on. However, since the Ministry of Finance has ceased the subsidy for biomass pellet in 2012, the growth rate of the fuel heating has been decreased.

Geothermal energy: mainly refers to the utilization of mid-to-deep geothermal energy, shallow geothermal energy, hydrothermal heat pump for building hot water and heating. Ground source, water source and other heat pump applications are the fastest growing fields of various geothermal energy utilization methods. In addition, the scale of mid-to-deep geothermal heating applications has increased rapidly. The mid-to-deep geothermal energy has become the main energy source for urban district heating in Xiong County, Hebei and other regions with rich geothermal resources. By the end of 2015, the national geothermal heated building area has reached about 500 million square meters.

Regulatory Framework and Management Mechanisms

The advantages of renewable energy heating include mature technologies and large-scale applications, but the scale of individual project is small, with non-commercial energy for the most part.

For the management of heating supply, China implements a concession operation system of heating for cities and towns is implemented in China. The heating enterprises shall sign contracts with the local governments through public bidding, participate in the construction, renovation and operation of the thermal power plants and the heating pipe network in cities and towns, and obtain the concession in specified scope and specified term. In other words, heating companies are monopoly in certain areas, namely heat source and heating pipe network integration operation management.

As China's heating price management authority does not belong to the central government, it’s difficult to develop a unified price incentive for heating at the national level. Based on the principles of unified leadership and hierarchical administration, the heating prices of cities in China shall be set up by the municipal administrative departments and be submitted to the provincial price competent authorities for approval.

The *Renewable Energy Law* stipulates that: ‘The price of heat or gas produced by using renewable energy and put in an urban pipe network shall be determined according to the principle of helping promote the development and utilization of renewable energy and the principles of economy and rationality and the provisions concerning price control power limits.’ But there are no documents in China to regulate the issue of incorporating the renewable energy heat source into the thermal pipe network. In order to join the existing urban heating system, distributed renewable energy heat source is facing a series of problems, such as whether the heat pipe network agrees to access, how to access, or how to determine the heating prices.

China has not yet introduced incentive policy for renewable energy heating. At present, renewable energy has become the main source of energy for district heating in some cities. But compared with fossil energy heating in the surrounding areas, there is not any price discount for renewable energy heating. For example, the mid-deep geothermal heating price in Xiong County, Hebei is 16 yuan/m^2 (heating season), the biomass CHP district heating price in Qixia, Shandong is 27 yuan/m^2 (heating season).

Beijing, Hebei and other regions with greater air pollution are vigorously carrying out clean energy transformation projects in rural areas, and are energetically promoting coal fired pollution control in rural areas, to support the transfer from the coal to clean energy. Renewable energy heating is a very important technology in replacing the coal fired. Compared with coal-to-gas or coal-to-power, however, the support isn't greater.

DistributedRenewable Energy Gas Generation

Status of Technology Development

Renewable energy gas mainly includes landfill gas, biogas, biomass pyrolysis gas, and other biomass gas. Biomass resources are scattered, which is not conducive to large-scale centralized utilization, so the production of biomass gas is for distributed applications.

Biogas, including household biogas and biogas projects, is obtained through anaerobic fermentation, using livestock and poultry manure, crop stalks, industrial organic waste water and residues and other organic matters as raw materials, with a methane content of 55%~65%. Compared with conventional energy sources, the application scale of biogas engineering is not large, so it also belongs to distributed energy. There are a great number of household biogas and biogas project in China, with mature technologies and wide range of applications.

Municipal waste landfill gas is the mixed gas produced through decomposition of anaerobic fermentation after landfill of domestic wastes, with methane and carbon dioxide as the main components. According to the different sources and compositions of the landfill wastes, there are 30%~55% of methane and 30%~45% of carbon dioxide in landfill gas. Urban waste landfill is the most basic disposal way of municipal solid wastes, with mature technologies and large-scale application.

Bio-natural gas is the product of purified and refined biogas and waste landfill gas. With more than 95% methane content, bio-natural gas can reach the quality standards of urban gas, and the project size normally is 10,000 cubic meters per day. With mature production technologies and commercial operation mode, bio-natural gas will become the key orientation of 13th Five-Year Plan in China, and the application fields will be extended to the automotive gas and natural gas supply pipe network. Through the following three methods, bio-natural gas can be included into the gas supply system: compressing natural gas transmission, incorporating into the urban gas pipe network and construction of independent regional gas pipe network.

Biomass pyrolysis gas is a type of combustible gas made from biomass resources such as forest and agricultural biomass, which is prepared with thermo-chemical conversion technologies, such as gasification or dry distillation. Its main components include methane, carbon monoxide, hydrogen, etc. The composition difference between biomass pyrolysis gas and natural gas is great, so it shall not be incorporated into the natural gas pipe network, but it can be used as energy raw materials for internal combustion generation unit.

A variety of biomass gas can be used for distributed applications. There are abundant biomass resources in China, of which crop stalks have nearly 800 million tons annual output, and livestock and poultry manure annually emit about 3 billion tons of carbon emissions. Coupled with plenty of urban wastes, domestic sewage, processing leftovers from agricultural products and industrial organic waste water and residues, China's annual biogas production potential can reach 100 billion cubic meters (equivalent to 60 billion cubic meters of natural gas), which is more than China's total imports of natural gas in 2015 (34 billion cubic meters).

The use of biomass resources varies greatly, including power generation, heating, gas and bio-ethanol production, so the planning and optimization of the resources is very important.

After 30 years of development, China's biogas production technologies have become mature, with a wide range of applications, including small-scale household biogas projects and biogas engineering projects. Due to many problems, such as uncontrollable raw material market and biogas final energy-use market, operation and maintenance difficulty of household biogas system, commercial operation mode of biogas engineering project and failing in incorporating the biogas into the gas network, the biogas projects are poorly performed in economy and stability.

Bio-natural gas is mainly distributed in the county towns, villages and towns in rural counties. From its production characteristics, bio-natural gas in the national gas system is clearly positioned mainly for county-level and below and mainly applied for distribution network. Relying on the development of biogas supply technologies and the traditional gas transmission and distribution technologies, the technologies of incorporating bio-natural gas into the gas supply system have been basically mature.

Regulatory Framework and Management Mechanisms

Renewable energy gas all comes from biomass. Biomass gas can be used directly for final energy consumers; household biogas and large-scale biogas can be used for civil cooking or be incorporated into the gas pipe network. At present, bio-gas applications are mainly used for final energy consumers, and there will be a series of problems on management system and standard specification when incorporating into the gas pipe network.

1)Gas management mechanism and pricing mechanism

At present, natural gas is the main gas in China with rapid speed of development, complete infrastructure, management and market system for transmission and distribution. Natural gas industry can be divided into three links: upstream production, midstream transmission and downstream sales. Natural gas prices include three parts: gas supply price, pipe transmission price and terminal market price. The midstream and downstream prices shall be formulated by the National Development and Reform Commission, and the downstream sales price will be determined by the local DRC. Natural gas pricing is mainly based on the core pricing method of 'allowable cost + reasonable profit'. The city-gate price is equal to ex-factory price of natural gas added with pipe transmission price; coupled with city transmission and distribution fees, the terminal market price is finally formed. At present, the natural gas in the midstream and downstream of China is basically monopolized by three large state-owned enterprises, namely CNPC, SINOPEC and CNOOC. Inter-provincial gas pipe transmission companies are mainly subordinate companies of CNPC and SINOPEC.

The oil and gas system reform program introduced in May 2018 clearly put forward to promote independent trunk pipe of large state-owned oil and gas enterprises step by step, achieve separate pipe transmission and sales, improve fair access mechanism of oil and gas pipe network, and fairly open the oil and gas trunk pipes and the pipe networks within and between provinces to the third party market entities.

The present situation of closed operation of gas pipe network in China changed in 2017. At present, the price for approval of natural gas pipe transmission in China is linked to the load rate. The load rate of pipe transmission enterprises is less than 75%, and the actual rate of return will be lower than the allowed rate of return. For the pipe companies with low utilization rate, the only way to obtain the allowed rate of return prescribed by the state is to open up the pipe to the third parties initiatively, so as to increase the load rate of the pipe. In August 2017, due to the load rate of the pipe companies of less than 75%, Zhangjiakou Yingzhang Natural Gas Co., Ltd. and Chongqing Three Gorges Gas (Group) Co., Ltd. issued a notice to welcome third-party enterprises to use their natural gas pipes to improve pipe utilization efficiency, making them the first companies to open up the pipe network to external companies.

The concession system is implemented in China's urban gas distribution. In order to be included in the natural gas pipe network, bio-natural gas must cooperate with the local gas operation enterprises to get through the channels between products and the market.

2)Problems of bio-natural gas grid-connection

First, the mandatory grid-connection system has not been implemented. According to the provisions of Article 16 of the *Renewable Energy Law*: 'Enterprises operating a gas or heat pipe network shall accept the access to its network of the gas or heat produced by using biomass resources, provided that the gas or heat meets the technical standards for access to the urban gas or heat pipe network.' But there is still a lack of operational management practices and implementation rules to ensure that the gas pipe network must acquire bio-natural gas for a good market environment, and promote technological progress and market expansion of bio-natural gas.

Second, lack of incentive policies. In recent years, China has vigorously supported the development and utilization of household biogas and biogas engineering. The technology of bio-natural gas production by biogas purification is mature; therefore, incorporating it into the existing natural gas pipe network is the only way to the large-scale application of biogas. As an emerging renewable energy technology, incorporating bio-natural gas into the gas supply system is also facing a lot of problems and challenges. The pricing mechanism for bio-natural gas and preferential policies for bio-natural gas shall be developed as soon as possible and be strongly supported and promoted.

Third, product positioning and planning issues. In general, the production of bio-natural gas depends on the distribution of raw materials, mostly in suburbs or rural areas with small-scale production; while the gas pipe and gas stations are located in areas with high population density. Although the resource potential of bio-natural gas is massive, but considering the basic principle of 'never competing with food for people', the development of biomass liquid fuel technology and market demands, the market positioning of bio-natural gas in near and medium term shall be the supplement of conventional natural gas. Bio-natural gas should be included in the existing natural gas pipe network for management and deployment, unified planning and rational layout, in order to integrate bio-natural gas and traditional gas supply system and reduce the cost of grid-connection and operation.

Fourth, standards and specifications. From the gas production, transmission and distribution and final energy utilization, China's gas supply system has relatively complete standards and specifications. Up to now, however, there are no standards or specifications for bio-natural gas access, technologies, and products. A minority of the existing standards and specifications for gas industry, such as the *Compressed Natural Gas for Vehicles*, can be applied to bio-natural gas, but existing standards do not meet the requirements to incorporate bio-natural gas into the gas supply system. For purification, refinement and distribution of bio-natural gas, bio-natural gas nanotubes and bio-natural gas terminals, lack of technologies, operation and product specification has seriously hindered the integration of traditional gas supply system and the bio-natural gas.

Distributed Renewable Energy for Transportation

There are two methods for renewable energy to provide transportation energy.

First, biomass liquid fuels, including bio-ethanol and bio-diesel, which can directly replace the liquid fuel for vehicle (gasoline and diesel), and the vehicle shall not be subject to major adjustments. Although the bio-ethanol for vehicle belongs to distributed applications, the production and sales of bio-ethanol are centralized.

Second, renewable energy supplying the power for electric vehicles. Driven by electricity, whether the electric vehicles are clean and renewable depends on renewable energy ratio in local power grid. Equipped with the distributed flexible load, an important power flexibility technology, the energy storage equipment of electric vehicles can meet the peak-regulating requirements for renewable energy power generation grid-connection through participating in ancillary services and demand-side response. Electric vehicle research will be discussed in hybrid energy technologies.

Summary

- The characteristics of distributed energy include high energy efficiency, low loss, less pollution, flexible operation and good economic efficiency. Based on the different energy requirements for consumers, the energy supply method of temperature alignment can be realized, in order to minimize the loss of the transmission stage, so as to maximize the energy utilization efficiency.

- Although the management mechanism is increasingly fair and open for small and medium-sized distributed energy companies, the growth of distributed energy is still facing a lot of difficulties. At present, the management system and mechanism of different energy varieties, such as power, heat and transportation fuels, are different. In the past, energy production and transmission belonged to a national monopoly, but it is now gradually being opened. A concession program is being implemented for heating, gas and refined oil production, and the energy project investment has been released. But most of them are restricted with scale qualifications, so it is still difficult for distributed applications.

- Grid connection issue for distributed energy resources still needs to be improved. The procedures of distributed renewable energy power generation project management and grid-connection management have been simplified, and the compulsory grid-connection requirements are also clear and operational. The bio-fuel ethanol has been integrated into oil network in targeted regions. However, the integration of renewable energy heat and gas into the energy network needs the support from institutional mechanisms.

- A variety of distributed renewable energy production technologies have become mature, with large-scale application conditions. Distributed renewable energy can provide electricity, heat, gas, liquid fuel and other energy varieties, to meet the final energy requirements in various fields.

- Distributed renewable energy can support higher levels of renewable energy integration. The capacities for existing distributed renewable energy heating, gas and transportation energy is still small, and its proportion in heat power network, gas network and transportation energy won't be high in the near future, making no effects on the operation of energy network. With the rapid development, the distributed renewable energy power can reach a higher proportion in some areas recently, which forms a certain challenge to the stable operation of power grid. But compared with centralized renewable energy power generation, the distributed generation can provide more flexibility and stability.

- The economic efficiency of the distributed renewable energy project is still one of the important factors restricting its development. In addition to the distributed renewable energy power generation projects, there are no explicit incentive policies and pricing mechanisms for renewable energy heating and gas supply. Although the pricing mechanism of bio-fuel ethanol project is clear, the subsidy has been cancelled and the economic efficiency of the project is poor.

- Multi-network integration can provide stronger support of efficiency and flexibility for energy system, and can support a higher proportion of renewable energy sources. Due to the heat network, gas network and refined oil network are all equipped with storage and regulation capacity, with help of the relevant technologies of electricity-heat coordination, electricity - transportation coordination, energy storage and demand response, the flexibility of the power system can be effectively improved.

20.2 Development Status of Multi-energy Coordination Technologies

Status of Technology Development

The interconversion of energy, also known as energy coordination, includes the coordinated integration of multiple energy technologies. Multi energy coordination technologies can realize a reliable energy supply system composed of electricity, heat, cooling and gas resources. The advantageous attributes of each energy can be highlighted due to the complementation of various energy sources so as to realize the high efficiency and adaptability of a multi- energy network.

Main multi-energy coordination technologies include the following aspects: multi-energy hybrid technology, electricity-heat coordination, renewable energy and electric vehicle coordination, and energy storage.

Hybrid Energy Technologies

The distributed hybrid energy system is a way of energy production and supply built on the user side. The system is developed to satisfy multiple energy consumption demands of end users (electricity, heat, cooling and gas resources) on the basis of comprehensively utilizing traditional and new energy with the support of integrated energy supply infrastructures, so that energy equipment can be increased to directly satisfy versatile demands of users through natural gas CCHP, distributed renewable energy and energy intelligent microgrid, thus to realize multi-energy coordination and comprehensive and gradient utilization of energy.

There are two major categories of hybrid renewable energy systems: renewable energy and fossil energy hybrid system — solar heating/fossil energy system, biomass boiler/coal boiler, geothermal energy/fossil energy system, wind power boiler/coal boiler, etc.; and multi-renewable energy hybrid system, including solar energy/geothermal energy heating & cooling system, solar energy/air source heat pump heating & cooling system and solar/geothermal/biomass boiler, etc.

Regional energy station is a typical form of the hybrid energy technology, which is widely adopted in Denmark, Estonia and Sweden. Its development is still in an early stage in China.

Regional energy stations in north Europe usually combine 2-4 thermal sources and technologies. Natural gas, solar energy, urban wastes, forest and agricultural biomass, geothermal energy, electric boiler and electric heat pump are widely applied depending on local resources availability and demands for energy consumption. Lots of regional heating systems use CHP units to provide basic thermal loads. Such units provide both thermal energy and generate power. Various CHP applications with wastes, biomass and natural gas should be supported by national policies.

Electric Heating Technologies

Turbine bypassing of CHP units, electric boiler and electric heat pumps are the main power-heat coordination technologies, which can realize highly flexible conversion between electricity and thermal power and ensure higher adaptation of the power system while significantly improving the flexibility of the thermal system, which is crucial to the high proportion renewable energy system.

These technologies are widely applied in Denmark. Regional heating stations (the typical application of hybrid energy and power-heat coordination) can enhance energy security for small cities and townships, which is also of critical significance to the adaptability of power system. The combination of heating and power generation has become a key consideration for developing high cost-effect heating and power supply system in the energy field.

Electric boiler and heat pump are the main renewable energy electric heating technologies. The core of renewable energy electric heating is to utilize abundant wind power and photovoltaic power to realize heat supply. Although the power supply for electric heating is not completely clean, the development and application of electric heating can strongly support the adaptability of heating and power system and the absorption of more power from renewable energy by the power system.

Electric boiler is a widely applied electrified heating equipment, with flexible operation. It is operated mostly during windy days or when electricity price is low, thus it’s an ideal peak regulation tool. Electric heating equipment capable of storing heat can use cheap off-peak electricity at night to accumulate heat for daytime, thus such equipment is also advantageous in balancing valley and peak of grid and reduce the electricity cost for heating. Heat pumps usually have a high initial investment cost and high system efficiency, which need a longer time to start up and depend on low-temperature thermal sources of regional heating system, e.g. industrial residual heat, seawater or wastewater. Different from the peak regulation of electric boilers, electric heat pumps can become the base load of power consumption.

Renewable energy electricity and electric vehicle coordination technology

Electric vehicles have great potential as a kind of distributed flexible load and energy storage facility. Energy storage of electric vehicle can satisfy the demand for renewable energy-based power generation and peak regulation of power network by participating in auxiliary services and responding to the demand side. With the increased proportion of renewable energy-based power generation in power system in the future, there will be higher demands for the flexibility of power system, and thus electric vehicle will become a flexible means of adjustment for power system. Meanwhile, the continuously increased proportion of renewable energy will lead to a higher percentage of clean energy in power consumption of electric vehicle, thus to lower the life-cycle emission of electric vehicle.

Electrification has become one of the most important reforms in transportation technologies in the world. In 2016, the global ownership of electric light passenger cars was over 2,000,000. China, the largest market of electric light passenger cars in the world, held a proportion of about 1/3 in the total ownership. The sales of electric vehicle in the Chinese market in 2016 exceeded 507,000, 1.81% of total car sales, including 409,000 BEVs and 98,000 PHEVs. In addition, there are about 3,000,000~4,000,000 low-speed electric vehicle and 2,000,000 in-service electric bicycles in China. China's electrification in the traffic sector grows the fastest in the world. However, China still relies on thermal power, and there have always been disputes over the environmental impact of large-scale application of electric vehicle throughout the life cycle.

In the progress of scaling up, there is great potential for coordinated development of renewable energy electricity and electric vehicle. Firstly, the well-organized introduction of electric vehicle will improve the absorption of fluctuated renewable energy electricity by power systems, reduce the dispose of wind and PV electricity, lower the cost for power generation and decrease the emission of pollutants and carbon. Secondly, the well-organized guidance for electric vehicle charging loads will reduce the load peak-valley difference of power systems, increase operation efficiency of generator units and save the investment in power generation capacity and fuel cost. Thirdly, flexible charging and discharging of electric vehicle can act as auxiliary service resources thus to lower the cost for such services. Fourthly, the effective management of charging of electric vehicle will, to some degree, avoid or reduce the cost for power transmission and distribution. In general, the coordination can reduce electric limits of new energy, lower overall emissions of electric vehicle and significantly improve operational and economic efficiencies of power systems so as to realize win-win development.

However, the realization of the environmental benefits of electric vehicle requires better integration of wind power, photovoltaic power and other renewable energy-based power. At present, China still heavily relies on coal power generation, the unit mileage emission of carbon by an electric vehicle is even higher than a conventional car in certain circumstances. For internal combustion engine technologies, if substitute fuels such as ethanol and biodiesel are used in the upstream, a significant reduction of CO_2 can still be achieved for cars with these engines, even higher than the emission reduction of electric vehicle at present. Therefore, although electric vehicle have the advantage of energy conservation and emission reduction in comparison with conventional diesel-fueled vehicles and can play a role of emission transferring, from the perspective of the entire life cycle, the emission intensity of BEVs is still higher than the oil-power mixed power and other substitute routes. Considering the high cost and the lack of infrastructures of electric vehicle, the selection of a proper technical route has become a focus of disputes in the development of new energy-based vehicle.

Energy storage technologies

Energy structure transition will have subversive influences on conventional energy system. Energy storage can help to solve increasingly serious imbalance between supply and demand caused by high penetration renewable energy. Energy storage technologies include heat storage and electricity storage.

1)Heat storage technology

There are short-term and seasonal heat storage in this field. Denmark's heat storage technologies develop rapidly and short-term heat storage units have been widely applied to heating systems, and seasonal heat storage has also entered into scale use. In China, heat storage is still in the R&D and pilot phase.

Heat storage technologies provide a flexibility to energy system (including power and heat systems), , which is critical to the optimization of energy system no matter from the perspectives of economy or environment. With heat storage units, CHP plants can reduce power generation in case of excessive power (in case of large winds, etc.) and increase power generation in case of high demand for power consumption. Heat is stored in proper units when supply exceeds demand for future use; otherwise when heat produced cannot satisfy the demand.

Short-term heat storage units are an important part of all CHP plants and regional heating stations in Denmark, where all large and small regional heating systems adopt short-term heat storage units, usually large-sized thermal-insulated steel tanks. In general, the heat storage capacity of such a unit is equivalent to the output of a heating plant running full loaded for 12 hours.

Seasonal heat storage system absorbed heat by solar heating collector during summer and supply heat to customer during winter. Seasonal heat storage units have been applied to many large-sized regional solar heating systems. The capacity of seasonal heat storage tank can be as high as 120,000 cubic meters. There have been researches on and application of heat storage pit, well heat storage and other seasonal heat storage technologies.

2)Electricity storage technology

Except for pumped-storage hydroelectricity, China’s most storage technologies is still in the R&D demonstration phase, comparing with countries with advanced storage technology. Regarding to energy storage applications, most projects are mobile communication base stations, emergency backup power supplies and off-grid projects in remote areas. The scale of grid-level energy storage is still small, and energy storage application for households, industrial and commercial entities at the demand side develop slowly due to limitations on power tariff. There are few applications of short-term heat storage technologies.

In the future, energy storage technologies will be oriented differently in various segments and development phases of power systems. It's necessary to conduct comprehensive researches on the energy storage development mechanisms in different segments and phases, find out the application scenario and economy of various energy storage technologies and clearly understand the stakeholders and commercial patterns of energy storage projects, in order to rationally optimize the role of energy storage at the power generation side, user side and grid side to provide the basis for formulating energy storage-related industrial policies in the future,.

Regulatory Framework and Management Mechanisms

The coordinated management and dispatch of energy will be the key technologies in future, which aims to realize highly efficient conversion between various types of energy and the interconnection of these energy sources at the demand side.

In a conventional energy system, energy planning for electricity, heat and transportation is usually independent from each other. Electricity network, heat network and transportation energy network (including oil products and LNG) are also independent and have different characteristics and issues under each management systems and mechanisms. They have rarely coordinated.

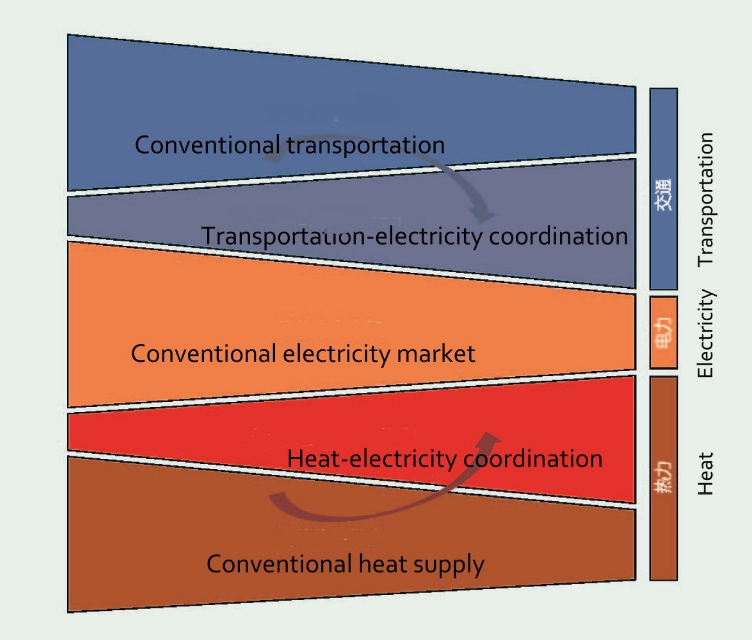
Each energy network has its limitations. Separate development cannot solve problems, such as, transmission, timeliness and peak-valley difference of the power network, results in limited grid absorption of wind power and photovoltaic power. The cost is very high although the development of electric thermal technologies bring along new paths to digest power from renewable energy. The limitation of the power network can be overcome by utilizing the network with large-scale energy storage such as heat network, and adopting energy interconversion technologies.

The multi-energy coordination has many advantages. For instance, thermal system has a huge inertia and some delay. There are numerous types of heat storage units and their cost and complexity are lower than power storage. The electrification of the traffic sector can reduce urban emissions including aerosols, dust, noise, etc. Coordinated dispatch, energy transfer and persuasive communication will improve peak-valley balance. The integrated operation of energy networks can provide a higher integrated utilization rate of energy based on energy control allowances.

The coordination among different energy can be realized by existing technologies. The use of efficient heat pumps, electric boilers, heat-storage electric heaters, etc. can coordinate power with heat; the electricity-to-gas or electricity-to-fuel technology can convert the only intermediate energy carrier of power — combustible gas — into heat, power or energy usable for transport. E-moving realizes the coordination between traffic and power.

Electricity is an important part for multi-energy coordination. Renewable energy electricity technologies are mature and applicable to many regions at a large scale. The remote transmission technology of electricity is also mature. The research and development of adaptation schemes in the power field is critical for energy structure transition.

Figure 20-1 Schematics of coordination among different energy fields



The transition of energy structure will definitely bring along a series of revolutionary changes in system and mechanism of production, transfer and distribution. On one hand, the scale development of renewable energy and the further development of electricity-heat and electricity-traffic coordination will enable the power sector to be the core of energy production. With the extensive development of distributed energy and intelligent electricity networks, there will be interactions between energy production and consumption, which will, to some extent, integrate and cause revolutionary impact on monopolies of certain energy industries, thus leading to deep changes in the property, enterprise, property organization, trading and pricing mechanisms of the entire energy supply system.

Table 20-1 Comparison of characteristics of different energy networks

	Energy transmission	Transmission scope	Existing problems in regulation	Interaction/conversion with electricity network	Flexibility
Electricity network	Instantaneous energy transmission, difficult large-scale storage	Long-distance transmission and local production and digestion	Peak-valley regulation; frequency modulation		Electricity storage Electric vehicle Electric boiler
Heat network	Higher system inertia than electricity network, large-scale storage in network	Mostly urban regional network	Peak regulation; balance of user heat	CHP; CCHP; electric-heating/cooling	Short-term and cross-sectional heat storage
Natural gas network		Long-distance transmission, urban networking	Peak regulation; balance between uniform supply of gas and uneven gas consumption of users	Natural gas power generation; CCHP Electric hydrogenation	Storable
Product oil network		Long-distance transmission, urban networking		Electric vehicle	Storable

Table20-2 Investments and market management mechanisms of distributed renewable energy projects

	Energy network	Investment of distributed projects	Distributed renewable energy Integrated access	Impact of renewable energy on energy network		Pricing mechanism and economy	
				Near-term	Long-term	Conventional energy	Renewable energy
Electricity	Trans-provincial monopolic operation	Decontrolled	Mandatory connect to grid, clear procedures and conditions, no scale limit Simplified procedures for distributed PV	Rapid development High percentage in certain areas in the near term, bringing along certain challenges	High-proportion operation, locally challenged; Valuation of distributed power and optimized distribution of power depending on resources, power distribution networks and loads	Priced by the central government Subject to the power transmission and distribution pricing system in the future	Preferential tariff, economic Fixed feed-in tariff for renewable power; fixed tariff subsidy for distributed photovoltaic power
Heat	No long-distance transmission, concession operation based on urban regional network	Decontrolled	Licensed heat supply by municipal government, mainly integrated operation of heating source and grid No regulation on connect to network	Huge application at the moment, mostly independent operations; Great potential for near-term, no impact on heat network	Advanced thermal adaptation technologies, great heat storage capacity, low cost, supporting higher percentages of power	Priced by local government or subject to licensed tendering pricing	No preferential heat price, poor economy Heat pricing subject to the tendering process for urban licensed operations

Fuel gas	Trans-provincial monopolic operation, urban licensed operation	Decontrolled	Urban fuel gas network licensed by municipal government; Lacking mandatory access management system and relevant technical standards	No access yet Small scale of access in the near term, no impact	Storage regulation, supporting higher percentages of power	Gas source and transmission pipeline costs priced by the central government, sales price determined by local government	No preferential gas price Investment subsidies for biogas projects
Product oil	Product oil operation licensing system	Decontrolled, qualification required	Specific mixing production and sales systems for biofuel ethanol; fixed-direction sales of E10 gasoline	Small scale of application, already feed in, no impact	Storage regulation, supporting higher percentages Limited by resources, planting land and technologies, uncertainty in percentage	Priced by the central government, subject to market pricing and integrated with international oil prices	Biofuel ethanol included into the gasoline pricing system and subject to governmental pricing Subsidies for grain-type ethanol cancelled, subsidies for non-grain type ethanol maintained

20.3 Energy Transition Trends and Features of Energy Systems of the Future

Energy Transition Trends

Energy is an important material basis for the development of human civilization, as well as an essential and basic condition for economic and social development. There are two major energy structure transitions in human history. The first transition is marked by the replacement of fuel wood by coal. The use of coal enables the wide application of steam engines, creating the essential condition for the first industrial revolution. The second transition happened at the end of the 19th century and the beginning of the 20th century, when petroleum replaced coal and became the predominant energy. Electricity was invented and widely applied, leading to the second industrial revolution.

For increasingly severe energy and environmental issues, some countries like Denmark and Germany put forward the concept of energy transition which focusing on the transition from fossil energy to the renewable energy, to achieve green growth and restructure a new and sustainable energy and socio-economic form, as the renewable energy technologies continuously become mature and widely used. The international community has gradually reached a consensus that the energy system is expected to undergo a profound transform in the next few decades, and a new energy transformation from high carbon to low carbon and high proportion renewable energy is also ready, The low-carbon transition of the global energy supply structure has become an inevitable trend.

From the perspective of energy utilization, this transition is not only a necessary means to guarantee the energy security and environmental pollution, but also the only way for human being to achieve environmental and sustainable development

Features of energy systemsof the future

Overall, the energy production side will continue to increase the proportion of renewable energy, and the consumption side will gradually form a high electrification, multi-energy hybrid and production-sales integration model. The entire energy transmission network (power, heat and fuel gas) will gradually enhance the smart grid and other energy network integration to support the transition and upgrading of the production and the consumption. The power trading market will keep opening up to finally realize free transaction.

1.High proportion of renewable energy covering all end user energy areas

High proportion of renewable energy is the main pillar and the most typical feature of the future sustainable energy system reform.

As early as 2010, Denmark issued the Energy Strategy 2050, proposing to “completely get rid of the consumption of fissile energy by 2050”. In 2011, Germany publicized its “energy structure transition strategy”, mentioned that by 2050, the proportion of renewable energy in final energy consumption would reach 60%, and power from renewable energy would account for 80% of the total power consumption. The European Commission on Energy issued the *Energy Development Roadmap 2050* in 2012, which proposed several development scenarios, where the proportion of renewable energy in total energy consumption reached a minimum of 55% and a maximum of 75%, in which renewable energy power generation accounted for up to 97% in electricity consumption. DOE carried out the Research on Future Power Energy in 2012, concluding that by 2050, renewable energy could satisfy 80% power demand of the U.S.

The production of renewable energy shows a trend of diversification, and will cover all end energy consuming areas, including electricity, heat, car fuels, etc. Non-water renewable energy-based power generation will grow fastest and scale largest. Distributed application-based renewable energy heating and fuels (solid, liquid and gas fuels) will have a significant rise, extending to cover full range of energy end needs including power generation, heating and vehicle fuels.

2.Popularization of distributed renewable energy leading to diversified energy producers

It is a foreseeable trend that energy production transits from centralized to distributed pattern, which is also the only way to realize energy structure transition.

Distributed energy will prevail in future energy system and become the main force of energy production. In the future, massive development and utilization of new energy will be a new pattern, and enterprises, organizations, shopping malls, residential buildings and individual households can invest in building their own solar, wind and biomass power generation facilities, including fuel gas CCHP and other power generating devices, to achieve the objective of "independent power generation for self-use, supplying excessive power to the grid and realizing power supply balance on the grid". All kind of enterprises can be actively involved, either as distributed power supply investors, or as professional service providers serve as microgrid communities or users to invest in new energy power generation or as power supply contractors. The owner or operator of a distributed power generation system (microgrid) shall have the right to purchase and sell power.

Jeremy Rifkin, author of *The Third Industrial Revolution*, mentioned in the book that a global-wide new energy revolution is rising, and distributed energy and the Internet are the core of the revolution. The third industrial revolution turns every building into a green building and microscopic energy station, an energy collector, and an energy producer that integrates the collecting and storing functions for power, heating and cooling, and realize networked storage and transmission and form an intelligent energy network system. In the future, people may establish a peripheral-like distributed intelligent power supply network via the Internet, enabling grid to become an energy-featured Internet. For tens of thousands of buildings, each can operate as an independent power generating station. Hundreds of millions of people will produce green energy from their homes, offices and factories and share the energy with others on line.

In future energy system, the distributed energy system will change the pattern that production and consumption are temporally and spatially separated, and build a new energy supply system that enables energy users to play the role of energy producer and supplier, leading to fundamental changes in energy production and supply, and significant variations of the social interest and human lifestyles.

Energy market management will be further market-oriented and standardized. The access to the whole industry chain of energy networks will be further relaxed, including energy networks such as power, heat and fuel gas, and each industrial chain segment such as energy production, transmission, distribution and operation. Energy production will see decentralization. Medium and small enterprises, family businesses and other forms of investments will have more opportunities. The units producing energy are diversified and will be both the producers and the consumers. Enterprises can actively take part in this progress, playing the role of both the investors of distributed power supply and the professional service providers of microgrid communities, energy storage and electric vehicle in the power market and the contractors of services for individual investment in new energy power generation.

3.Energy system becoming more efficient and adaptive with the support of multi-energy coordination technologies

It's estimated that, by 2030, the percentage of fossil energy in energy production will drop significantly, and renewable energy will become one of the main force. The integration of grid with heat and fuel networks has started. Power-heat coordination (CHP, electric heating, heat pump, etc.), power-traffic coordination (electric vehicle), energy storage (thermal and electric) and other new technologies are rapidly developed, resulting in a significant improvement in energy system efficiency.

By 2050, renewable energy will become the main force of energy production. The proportion of renewable energy will be further increased, energy production will be further diversified and the percentage of distributed energy will be further improved. Energy production and sales will be integrated and self-consumption will widely spread. Energy network will be highly synchronized with the Internet and the Internet of Things. Free transaction of energy will be realized on networked energy transaction platforms participated by energy producers, producers & sellers and users.

Future energy system will take power system as the hub to realize interconnection with power, heating, natural gas and traffic systems, and will connect with large-scale distributed power supplies and energy storage integrated system. By improving energy system efficiency and introducing higher percentage of renewable energy, future energy system will realize the supply and demand interaction and satisfy versatile demands of users.

4. Smart Integration for efficient operation and service of energy systems

Smart Integration is an important feature of future energy system. Smart integration means the efficient integration of power systems with the information system and the Internet to form a safe, secure, and efficient energy internet.

With the development and operation of medium and small-scaled renewable energy power generation, distributed power generation and microgrid projects, especially with the application of the intelligent power network and the establishment of the next generation power market system, the power market participants become diversified, including not only conventional power generation, transmission, distribution and marketing enterprises but also emerging investors, new platforms and third-party service providers, energy storage, microgrid, electric vehicle V2G operation service, forecast and predicting service, and intermediary of power market who require the support and guarantee of highly intelligent system.

In future energy system, the extensive application of distributed energy and the diversification of energy investment will promote significant increase in quantities of energy producers, which will result in a substantial increase in the scale of energy database. An intelligent system can realize real-time monitoring and services of energy production, transmission, distribution and consumption, and generate energy big data covering various energy products and services. Virtual and physical networks will be combined to fully utilize such big data and integrate renewable energy utilization, energy efficiency improvement, energy storage and grid technologies into the energy supply system, and support free communication between users and power sellers and between power sellers and power producers. A highly intelligent energy data system can realize the interaction and cooperation between energy producers and consumers via demand-side response and other policy mechanisms, and improve the efficiency and service capability of energy system via multi-energy coordination and other policies so as to build a system growing from individual energy network to energy Internet.

Policy Mechanism for High Penetration of Distributed Renewable Energy

1)Simplifying project management procedures and establishing effective interdisciplinary coordination mechanism

Distributed energy projects are small scale, large quantities and widely distributed. The existing market access system, project management system and transmission-distribution management system are designed for centralized energy, which can hardly support the high-percentage utilization and development of distributed energy. The simplification of the management procedure is the basis and a necessary condition to realize scale development of distributed energy.

Simplified project management and grid-connection management procedures of distributed renewable energy generation and formulate simplified management procedures for distributed heat and gas, based on experiences in distributed PV. Encourage scale application of distributed renewable energy projects without construction scale limit, to guarantee the market space for distributed power generation; make sure distributed power generation projects are automatically qualified for subsidies once construction acceptance and grid connection are finished; and implement simplified grid-connection management procedures. Promote one-stop services nationwide, the business counters shall accept the grid-connection applications, and refine the service procedures and requirements to ensure distributed renewable energy generation get grid-connection in a timely manner. Make clear the priority and full amount power purchase, encourage self-production and self-consumption and connect the excessive power to the grid. Implement simplified management procedures for distributed heat and gas supply; guarantee the market access to thermal and fuel gas networks for distributed renewable energy; and simplify project management, grid-connection management and operation service management of renewable energy-based heat and gas supply projects.

Establish effective interdisciplinary coordination mechanisms based on requirements of multi-energy coordination development. To achieve the energy structure and energy demand of the high proportion of renewable energy, need to coordinate energy production and consumption; rationalize management responsibilities among government authorities, including the relationship between energy administrations and urban, rural and traffic authorities as well as the relationship within different energy system including power, thermal, fuel gas and product oil networks ; coordinate strategic planning, resources management, renewable energy products market access and transaction management, pricing formation mechanism and technologies standard system establishment and renewable energy statistics, reporting and reviewing system. Adhere to the objective of matching the reform of renewable energy sector with reforms in other fields; and enhance coordination in reforms among different sectors and promote market-oriented development of multi-energy coordination technologies.

2) Creating an open and fair market and guaranteeing the priority of distributed renewable energy.

Adhere to the market-oriented reform and eliminate the status quo of market access and create an open and fair market. Future energy market systems and mechanisms should in accordance with the requirements of the high-penetration of renewable energy development; achieve significant energy system reform; adhere to the market-oriented reform, eliminate market access restrictions, open competition, break administrative monopoly (especially the exclusive purchase and transaction/dispatch of power) and supervise natural monopoly and public welfare segments. Eliminate the market access limitations on power grids, heat networks, fuel gas networks and other energy facilities; encourage social capitals to invest in energy facilities; promote the combination of centralized and distributed utilization of energy and power in production and supply; and establish a new centralized-and-distributed energy market mechanism and system, and a development and management system adapting to the widely application of distributed energy.

Specify the requirement for full-amount mandatory grid-connection and guarantee the priority of distributed renewable energy. Guarantee the right of renewable energy to connect with energy networks; further ensure the grid-connection superiority measures for distributed renewable energy generation; guarantee the full-amount and priority purchase right of fuel gas and heat from distributed renewable energy; introduce and update relevant regulations and implementation rules according to the *Renewable Energy Law*, following the guidelines of local access, full-amount purchase and prior grid-connection and different needs of power, heat and fuel gas; guarantee renewable energy enterprises from various systems can participate in the production, transmission and distribution and operation of energy chain.

In the field of electricity generation, build up an open-type grid operation management systems adaptive to distributed electricity. Further implemented simplified and prior project management and grid-connection management systems for distributed photovoltaic power generation and expand to biomass power generation and other distributed renewable energy-based power generation projects; speed up the pace of reform to allow diversified market forces and projects to enter the market; open up the market access scope for owners to enable industrial and commercial enterprises and individuals can invest in and operate distributed power generation; soften the terms on access to the power distribution and selling market; encourage various market forces to invest in and operate power distribution networks and to engage in power selling business, establishing an open and tolerable power market adaptable to distributed power generation and the smart grid. With the scale development of distributed user-side photovoltaic power generation and distributed wind power, power networks will transit from previous "transmission to distribution" to bidirectional flow, and the boundary between grid and distribution networks will be more indistinct. On the basis of coordinated planning of grid and distribution networks, the network management level adapt to flattening and networked power systems and to ensure the openness and competition in power generation and consumption. The power networks should be open to all users and power generation players in a fair and non-discriminatory manner.

In the fuel gas and thermal fields, specify the access right and priority of renewable energy. Enterprises operating fuel gas and heat pipe networks shall accept fuel gas and heat from distributed renewable energy in a full-amount and prior manner. Grid-connection standards for urban fuel gas and heat pipe networks shall be introduced as soon as possible to guide standardized production and technical advancement. Support and encourage enterprises operating fuel gas and heat from renewable energy to take part in licensed operation management of urban or regional heat supply pipe networks, fuel gas pipe networks and energy stations. Soften the terms on market transfer to provide priority for these enterprises to obtain franchise rights.

3) Carrying out distributed energy assessment and planning, specifying their status and value

The status and value of distributed renewable energy in China is not clear now. Although some results in the development of distributed renewable energy has been achieved the development of distributed renewable energy in China is still in the initial phase, lacking of clear understanding of the status, development potential, development objectives and paths of distributed renewable energy. In future energy system, China should include distributed energy into the national energy development strategy with clearer structure and make it an integral part of China's energy system.

Carry out in-depth assessment on potentials of distributed renewable energy and find out the optimal value of distributed projects. Comprehensively assess development potentials of distributed renewable energy based on the distribution and local urban development planning, energy production, transmission & distribution and energy end demand, to provide instructions for developing distributed renewable energy projects in most suitable places with most suitable manners throughout energy networks.

Integrated into the national planning system. Set up the idea that distributed renewable energy get priority and development together with power generation, heating and fuel gas; include distributed renewable energy into the national renewable energy developing planning, power development planning, etc.; fully understand the value of distributed energy and include them into the energy development strategy; and enhance the top-level design for distributed energy and set the role of distributed energy accurately.

Integrated into urban planning system. It’s essential to integrate distributed renewable energy projects with regional and urban energy system; take distributed renewable energy projects as an integral part of urban energy planning during new area development, old are reconstruction and industrial park/zone development; include distributed renewable energy power, heat, fuel gas and product oil into the urban energy system; improve energy security via the integration of multiple energy networks; combine the development of distributed energy with energy demands from urban development and ensure there is no differentiation for users in consumption of power, heating and cooling energy .

Specify the orientation of renewable natural gas and coordinate it with overall fuel gas planning. Renewable natural gas shall be oriented as small scale, distributed application, and the supplement and substitute of conventional fuel gas. It’s necessary to include renewable natural gas into the flue gas pipe network for management and dispatch to guarantee the stable gas supply to users, reduce the operational cost of individual project and improve efficiency of energy system at the same time. Where production and loading conditions are met, regional gas supply networks can be established nearby to supply gas for the neighborhood. According to availability of resources and load demands, research and analyze regional distribution and value of renewable natural gas, prepare development plans and coordinate with the fuel gas plan, and provide guarantee for grid-connection and prior utilization for renewable natural gas.

4) Establishing market and supply-demand oriented pricing and incentive mechanisms to improve economy of projects.

China has set up and gradually improved the pricing mechanism for renewable energy electricity, fixed feed-in tariff for renewable energy electricity, and preferential fixed subsidy for distributed PV electricity, which have actively promoted the rapid growth of renewable energy electricity. However, there is still no pricing and incentive mechanism for renewable heat and natural gas, leading to poor economy of distributed projects. The existing loans, investment and financing mechanism are hardly to adapt to the needs of distributed projects. Business model is immature, which affecting confidence and enthusiasm of investors.

From the near term, it's urgent to develop the pricing mechanism for renewable heat and natural gas, implement preferential incentive policies to improve economy of projects.

Verify and approve national instruction prices/subsidies, under the principle of the price of renewable not lower than natural gas. Issue the incentive price based on the level of application and conditions for relevant technologies, especially for solar heating, biomass CHP, biomass boiler heating, medium and deep-layer geothermal heating, biogas and biomass natural gas projects that are qualified for scale development. Establish the regular price adjustment mechanism to promote technological progress and cost reduction; and explore the conditions and system measures for assigning quotas for renewable energy in the fields of gas supply and heating, and gradually increase the proportion of renewable energy.

Issue preferential national loan policy to support small and diversified distributed project investors. Give full play to the role of national policy banks and include distributed renewable energy projects into the key support area; and set up special preferential loans and long-term and low-interest rate loaning support.

From the middle and long term, it's required to establish the market and supply-demand oriented pricing and regulation mechanisms to encourage the development of distributed renewable energy.

Establish a more accurate electricity pricing mechanism to encourage distributed renewable energy to take part in market competitions at the same time reflect the real value of distributed power generation. The current electricity pricing mechanism is mainly for quantity prices based on electricity quantity transaction. With the development of wind, photovoltaic power and other large-scale flexible loads, the one-track pricing mechanism can no longer meet the requirements for flexibility in power generation and consumption and the security for power generation capacity. The suggestion is to introduce the multi-track pricing mechanism to implement separate pricing for capacity, electricity quantity and ancillary services so as to encourage capacity and ancillary services, improve flexibility of power and reflect the real value of distributed power. Promote the power market reform ; ensure the fairness and non-discrimination of the grid; break the bidirectional monopoly pattern that grid enterprises are the sole buyer and seller; create competitive markets; according to the supply and demand change,establish pricing systems for power generation and consumption markets based on different time periods and regions, design the pricing mechanism for power transmission & distribution wheeling charges that encourage the application of distributed power; encourage distributed power to participate in local power supply directly; and establish and standardize power transaction organizations.

Explore and establish the pricing mechanism and system for multi-energy coordination. Encourage energy storage and other flexible resources to participate in market transactions to form a price-market interlink mechanism including power, heat, fuel gas, car traffic and other energy products; promote flexible conversion between energy products and systems; and guarantee efficiency, adaptability and security of energy system.

Reform and innovate the national loaning, investment and financing systems. Explore the cooperation between national policy banks and commercial banks; national policy banks should play the role of guiding and leading, and provide long-term and low-cost financial support for more distributed energy projects.

References:

1. Li Liying et al. "The Formation Evolution of China's Energy System and the Development of Distributed Energy". *Distributed Energy*. Feb. 2017, Vol. 2, Issue 1.

2. China Gas Association. "A Research on the Mechanism of Including Biomass Natural Gas into the Gas Supply System". Dec. 2015.

3. Gao Shiji, Guo Jiaofeng et al. "Energy Internet-based Promoting Energy Structure Transition and Systematic Innovation in China". China Development Press. Aug. 2017.

4. Jeremy Rifkin. *The Third Industrial Revolution*, CITIC Press. 2012.

5. Historical and current U.S. strategies for boosting distributed generation, Travis Lowder, Paul Schwabe, and Ella Zhou, National Renewable Energy Laboratory

6. China Renewable Energy Industries Association. "A Research on the Investment and Financing Mechanism for Distributed Photovoltaic Projects in China". 2014.

7. Energy Research Institute the National Development and Reform Commission. "A Research on the Development Pattern and Operation Mode of Distributed Power Generation". 2012.

8. World Resources Institute. "Policies on and Practices in Developing Distributed Clean Energy". May 2017.

9. Energy Research Institute the National Development and Reform Commission. "Overall Report of the Research on Development Scenarios and Paths of High-percentage Renewable Energy by 2050 in China". April, 2015.

21 Carbon Market and Renewable Energy Development

21.1 Scope and methodology of research

Scope of research

Both carbon market and renewable energy are broad concepts. To analyze the relationship between the two, entails clarification of their exact connotation in the first place.

Carbon market. Carbon market is a system under which government, for the purpose of achieving quantitative mitigation targets, allocates total carbon emissions quotas to main emitting enterprises, specifying enterprises' actual emission amounts should under no circumstances exceed their designated carbon emissions quotas; in the meantime, government may allow enterprises to obtain quota through market transactions, in a bid to enhance quota allocation efficiency and reduce CO_2 emissions mitigation costs. Carbon markets can be divided into two types, i.e. voluntary and mandatory markets, by the nature of mitigation targets undertaken by market contractual entities. As mandatory markets (also called regulated markets) normally have stronger and more binding force on targets, larger market sizes and more distinct potential influences on renewable energy development, this research will focus mainly on mandatory markets. In accordance with different type of transaction varieties,mandatory markets can be further divided into allowance-based and project-based markets. Judging from current development status of the carbon markets worldwide, allowance-based markets are larger in size than project-based ones.

Renewable energy. There is a diversity of renewable energy technologies, which correspond to different development stages. The cost of these technologies also differs vary greatly from one to another. Hydropower and biomass-based power generation technologies are already mature; technologies such as onshore wind technology and solar PV power generation technology are currently developing very fast, with their technological costs declining rapidly. They still have a high development potential in the future and are expected to become an integral part of renewable energy; off-shore wind and solar thermal power generation technologies in China, on the other hand, are still in an early stage of technical application, and facing barriers such as high costs and immature technology. In this research we will mainly focus on two types of renewable energy technologies, i.e. onshore wind and solar PV power generation and how a carbon market impacts their competitiveness. These two technologies become the dominant sources of clean energy development in the scenarios described in Part 2 of this report.

Currently, the biggest intersection of carbon market and renewable energy is the power industry. All major renewable energy sources are utilized in form of electricity. For instance, 90% of China's commercialized renewable energy application is achieved through electricity generation.Meanwhile, the power industry as a major source of GHG emissions constitutes a key industry of all national carbon markets. In addition, the global low-carbon energy transition requires the power industry to play a pioneering role. Low-carbonization of power supply,in combination with increasing electrification of final energy consumption in all sectors, have made the power industry a priority for the global low-carbon transition especially in its early stage. This is also in alignment with the scenarios introduced in Part 2 of this report. Thus, the quantitative analysis part of this research will mainly focus on the power industry.

Research methodology

The following methods are adopted in this research:

A combination of theoretical and empirical analysis. The relations between carbon market and renewable energy development may differ to varying degrees, depending on specific time and location differences. Firstly, carbon market itself may undergo different stages from creation, development through maturation; secondly, renewable energies may differ in variety and from one region to another. Analyzing the interaction mechanism between carbon market and renewable energy development from a theoretical perspective helps us to get away from various existing complicated factors we discussed above and obtain a true understanding of the fundamental relations between the two. In addition, internationally as some carbon markets have already been running for many years, analysis from an empirical perspective appears to be a more convincing way to explore the association between carbon market and renewable energy development.

Dynamic analytical perspective. In different stages, the association between carbon market and renewable energy development displays different characteristics. Firstly, as carbon market gradually develops into more mature forms, the increasingly stringent requirements for controlling carbon emissions are to be embodied in factors such as coverage scope and transaction price of carbon market; and secondly, technological costs of renewable energy development will witness continuous decline because of aspects such as scale effects and learning effects. Analyzing their interplay from a development perspective may help us grasp the tipping point at which certain changes take place owing to their mutual effects.

Model-based quantitative analysis. This involves a modeling method to discover the prospective effects of carbon market on renewable energy development quantitatively. First is to build a LCOE model to compare LCOEs for coal-fired and renewable-based power generation, and find out the desired carbon market price levels when LCOEs for the two are in a balance; and second is to build a power cost bidding model to analyze prospective bidding strategies that may exist in the power market for coal-fired and renewable-based power generation, and find out carbon market price levels when costs for coal-fired and renewable-based power generation are in a balance. Based on analytical results of the two models mentioned above, in combination with analysis of carbon market price levels in the future, we may draw a conclusion about to what extent carbon market may have an influence on renewable energy development in the future.

21.2 Development background, current situation and trend of carbon market

Background for emergence

The carbon market is designed for addressing global climate change calls for controlling and mitigating carbon emissions, in a bid to advance the global energy transition. Long-term scientific observation proves that significant climate changes, mainly characterized by global warming, have been taking place worldwide.

From 1880 to 2012, average global surface temperature raised by approx. 0.85℃. The 1983-2012 period was marked as the hottest three decades in the past 1,400 years[126].Global climate change result in rising sea levels, frequent climate disasters like flood and drought, reduced agricultural productivity and ecological function losses, which may cause serious adverse effects on the survival and development of human society. Studies have shown that global climate change is now attributed to approx. 1.6% of the world's annual GDP[127]. If no action is taken, then the overall value of risk associated with climate change will be equal to at least 5%-20% loss of the world's annual GDP[128]. The IPCC Fifth Assessment Report further suggests GHG emissions released by human activity are the main reason for climate change. Of all, CO2 is the leading type of GHG, accounting for over 75% of all emissions[129]. Of all sources of CO2 emissions, fossil fuel burning is the largest source of emissions, accounting for over 90% of total CO2 emissions. Hence, the primary factor resulting in climate change is CO2 emissions attributed to energy activities. Consequently, advancing the energy transition and reducing CO2 emissions attributed to fossil fuel burning is a key pathway towards climate change mitigation. The international community has reached a political consensus on "holding the increase in the global average temperature to well below 2 °C above pre-industrial levels[130]". Meanwhile, the IPCC report proposes a pathway for achieving the goal of 2 degree limit for temperature rise, that is, pursuing efforts to reach global GHG emissions peak around 2020, reduce emissions to 40%-70% of the 2010 level by 2050, and realize zero emission by the end of this century. Considered as hard constraints on carbon emissions, these targets necessitate a profound transition towards a low-carbon, even zero-carbon global energy system that is currently being dominated by fossil fuels.

Major countries propose their carbon reduction targets and explore low-carbongrowth models. As energy lays an important material foundation supporting our socio-economic development, global climate change is essentially a development topic of importance to human society. Against the backdrop of increasingly severe climate change challenges, human society never stops searching for new development patterns that may help us to

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[126] IPCC (Intergovernmental Panel on Climate Change)WG1 Fifth Assessment Report

[127] CMA website: http://www. cma. gov. cn/2011xwzx/2011xqhbh/2011xdtxx/201209/t20120927_186288. html http://www. cma. gov. cn/2011xwzx/2011xqhbh/2011xdtxx/201209/t20120927_186288. html

[128] Stern Review

[129] IPCC WG1 Fifth Assessment Report

[130] Hereinafter referred to as the "2 degrees Celsius temperature rise target".

realize bigger, better and more sustainable growth under the constraint of increasingly scarce space for carbon emissions. It is in this context that low-carbon development as a new development pattern came into being, and emerges as a global development trend in today's era. To actively address global climate change, countries around the world put forward their own carbon emissions control and low-carbon development targets one after another. Developed countries, like the EU and US, not only proposed their 2020 carbon emissions control targets[131], but also raised their own emissions reduction targets for an extended period of time. The EU, for example, proposed a target of reducing its carbon emissions by 40% in 2030 and further by 80%-95% in 2050, compared to its 1990 level; Germany proposed a target of reducing its total emissions by 55% and 80%-95% in 2030 and 2050, respectively, compared to its 1990 level; and the US proposed a target of reducing its total GHG emissions by 26%-28% and over 80% in 2025 and 2050, respectively, compared to its 2005 level. In the meantime, developing countries like China, South Africa and Brazil all set out their own nationally determined action targets on low-carbon development. For example, South Africa proposed a target of making its carbon emissions peak during 2020-2025; Brazil proposed a target of reducing its carbon emissions by 36.1%~38.9% in 2020, compared to those in the normal scenario; and China proposed a target of making the country's carbon emissions peak around 2030 and pursuing efforts to make emissions peak as early as possible.

Carbon market is a policy tool adopted by major countries to pursue the realization of their carbon emissions control targets based on market-based mechanisms. Under the premise of economic and social sustainability, pursuing the realization of such targets on the basis of guaranteeing energy supply and reducing CO2 emissions requires us to enable a revolutionary transition of the old socio-economic development patterns and energy development models. This mainly includes two aspects: First is to transform traditional development patterns, improve energy efficiency and reduce energy consumption; and second, is to develop non-fossil fuels and low-carbon energies and promote low-carbonization of the energy structure. This has also become a key direction for countries around the globe to advance a new round of energy revolution in the context of global climate change. Aside from enhancing energy efficiency and developing renewable energy, many other systems, carbon market being one of the most important one, have been employed to advance low-carbon development.

Current development situation and trends

Carbon markets have been begun to take shape in recent years in several locations:

In terms of scope, carbon markets already cover 40% of the world's GDP and 15% of its carbon emissions. The world's first major carbon emission rights trading system was EU ETS (emissions trading system), which was put into operation in 2005. By 2017, 18 carbon trading systems across four continents, at the levels of megacity (e.g. Tokyo), state/province (e.g. California of the US and Ontario of Canada), country (e.g. New Zealand,

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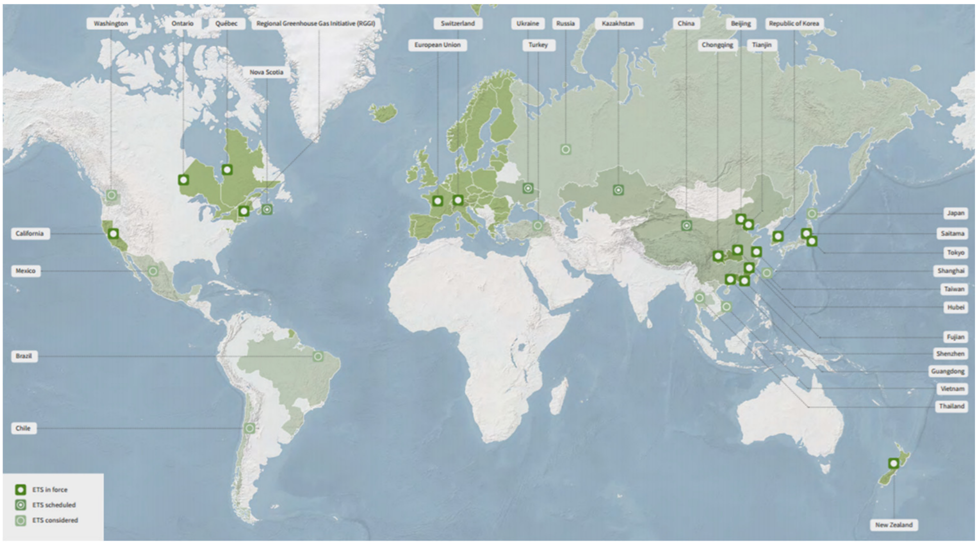
[131] United Nations, FCCC/TP/2013/7

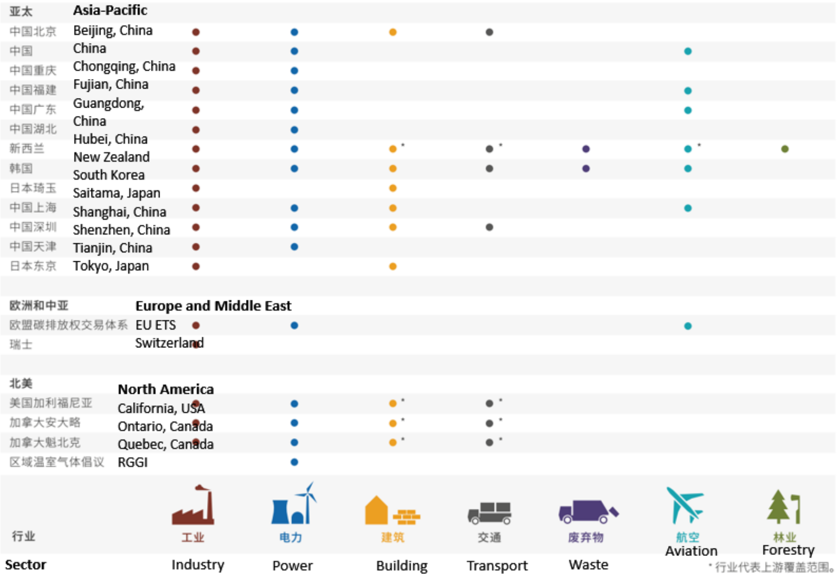
Switzerland) and even supranational organization (e.g. the EU), have been consecutively formed. Currently, carbon transactions are being carried out in 35 countries, 13 provinces/states and 7 cities. In addition, some other economies, like Russia and Brazil, also consider making carbon market as a vital tool for coping with climate change.

Figure 21-1 Regions already engaged in or ready to launch carbon trading around the globe.



Carbon markets have so far covered a wide array of sectors, including industry, power, building, transportation, waste, aviation and forestry. Most carbon markets cover industry and power sectors (the US' Regional Greenhouse Gas Initiative, or RGGI, only covers the power sector), while most carbon markets in Asia and North America cover building and transportation sectors. Aviation as a special contributor of emissions is covered by carbon markets of China and the EU as well.

Figure 21-2 Industries covered by major carbon markets worldwide



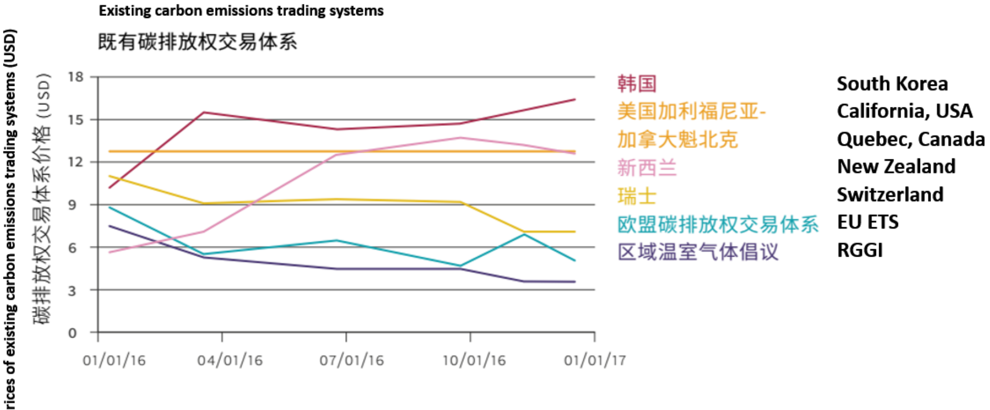
		工业 Industry	电力 Power	建筑 Building	交通 Transport	废弃物 Waste	航空 Aviation	林业 Forestry
亚太	**Asia-Pacific**							
中国北京	Beijing, China	●	●	●	●			
中国	China	●	●				●	
中国重庆	Chongqing, China	●	●					
中国福建	Fujian, China	●	●				●	
中国广东	Guangdong, China	●	●				●	
中国湖北	Hubei, China	●	●					
新西兰	New Zealand	●	●	●*	●*	●	●*	●
韩国	South Korea	●	●	●	●	●	●	
日本琦玉	Saitama, Japan	●		●				
中国上海	Shanghai, China	●	●	●			●	
中国深圳	Shenzhen, China	●	●	●	●			
中国天津	Tianjin, China	●	●					
日本东京	Tokyo, Japan	●		●				
欧洲和中亚	**Europe and Middle East**							
欧盟碳排放权交易体系	EU ETS	●	●				●	
瑞士	Switzerland	●						
北美	**North America**							
美国加利福尼亚	California, USA	●	●	●*	●*			
加拿大安大略	Ontario, Canada	●	●	●*	●*			
加拿大魁北克	Quebec, Canada	●	●	●*	●*			
区域温室气体倡议	RGGI		●					
行业	**Sector**	工业 Industry	电力 Power	建筑 Building	交通 Transport	废弃物 Waste	航空 Aviation	林业 Forestry

* 行业代表上游覆盖范围。

Sector denotes coverage scope of upstream industries.

Carbon market prices in South Korea’s carbon market reached US$17/t in early 2017; prices in carbon markets of the US State of California, Canadian Province of Quebec and New Zealand are also relatively high, all exceeding US$12/t; prices in the EU and Swiss carbon markets stay in the range of US$5-7/t; and the RGGI price is currently at a low level of just above US$3/t.

Figure 21-3 Quota prices of carbon markets currently in operation



加州-魁北克省、欧盟、区域温室气体倡议和瑞士等的碳价是指拍卖结算价格，而新西兰和韩国的碳价是指二级市场价格。

Carbon price of California-Quebec, the EU, RGGI and Switzerland refers to auction settlement price, whilst that of New Zealand and South Korea refers to price in the secondary market.

Carbon markets receive active support from many countries and international organizations. Judging from current development trends, carbon markets are likely to emerge as a major policy tool for countries around the globe to achieve their carbon emissions control targets and a key pathway for global cooperation in low-carbon development in the future.

Firstly, carbon markets have been playing an important role in advancing the realization of carbon emissions control targets.Identifying emissions reductions should always consider macro-economic changes as well as the emission reductions under a business-as-usual scenario. Emission intensities in many sectors, for example, have been falling for decades, including before the creation of ETS systems.Given properly set caps, ETS schemes can be very strong tools, as the caps can put strong limits on total emissions.Some empirical evidence can be obtained by comparing emission trajectories between individual states of the US. If effective, California and the RGGI states should reveal steeper downward trends in emission than the other states. The trend in total emissions in California and the US average are pretty similar, while the RGGI states have reduced emission much more strongly than the US average, but this trajectory existed before the introduction of their ETS scheme. Per capita emissions are far lower in California and the RGGI, compared with the average of the other US States, although it should be mentioned that as the decreasing trends might not be only caused by carbon market as the decreasing trend also starts earlier that the introduction of ETS scheme.

Figure 21-4 US energy-related carbon dioxide emissions (2000=100). Source: (EIA, 2017).

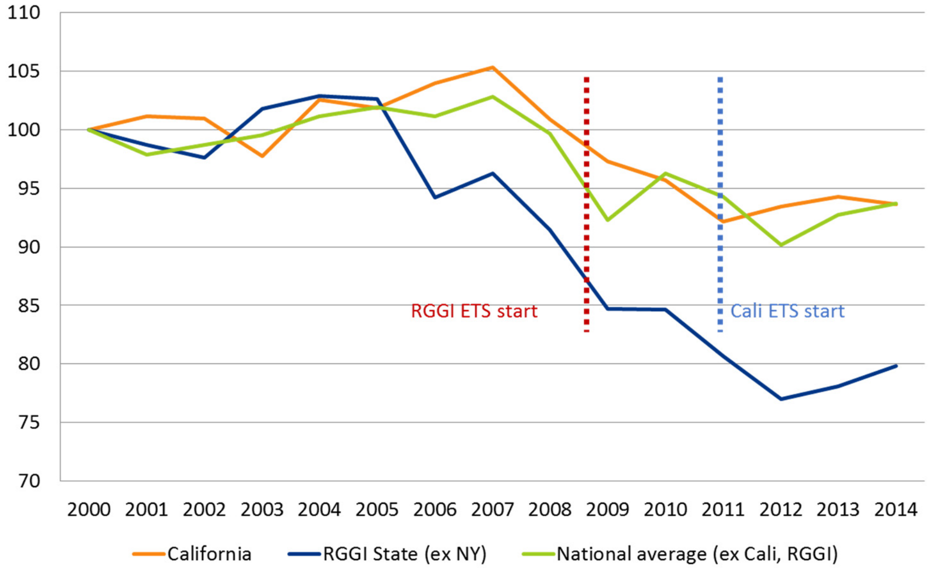
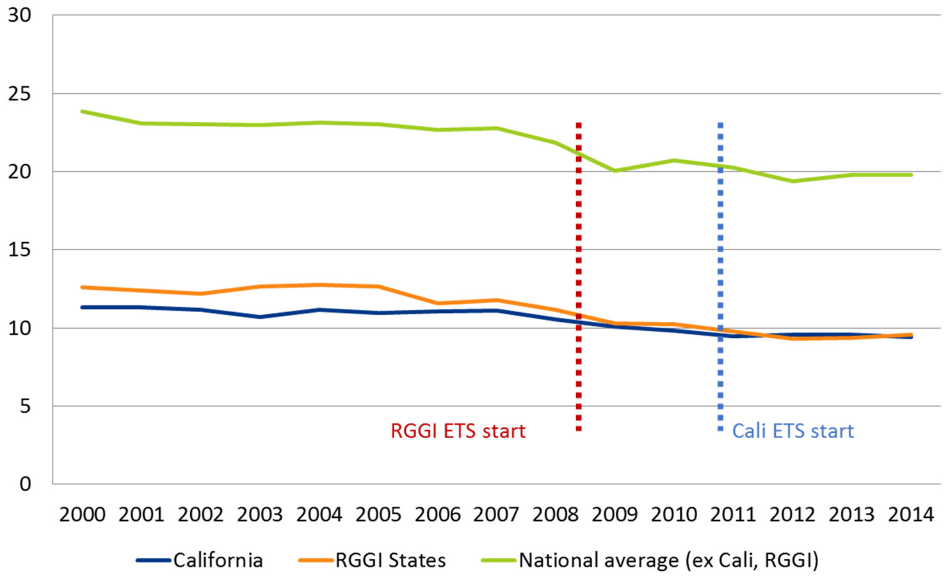


Figure21-5 US energy-related carbon dioxide emissions, tonne of CO_2-eq per capita. Source: (EIA, 2017).



Secondly, carbon market is expected to become an important policy measure for countries around the globe to reduce their emissions in the future. According to IETA statistics, out of nearly 200 countries that submitted their INDC documents to the United Nations, more than 2/3 proposed adopting market-based emissions reduction mechanisms, such as carbon trading, to achieve their INDC targets.

Furthermore, carbon market is included as an important part of the Paris Agreement to advance international cooperation in emissions reduction. The Paris Agreement, which was signed in 2015 and came into force in 2016, clearly proposes to support the use of carbon markets as a way to strengthen international cooperation in mitigating global climate change. Article 6 of the Paris Agreement stipulates that [participating] Parties have the right to pursue voluntary cooperation in the implementation of their nationally determined contributions. For example, countries implementing a carbon trading system may link their respective systems together, and include the amount of emissions obtained through transactions into their INDCs. In addition, this article describes another market-based cooperation mechanism for participating parties, that is, a mechanism to contribute to the mitigation of GHG emissions and support sustainable development. International organizations such as the World Bank have also been striving to advance the development of carbon markets worldwide, proposing a target of doubling the share of emissions covered by carbon markets in global total emissions by 2030, from the current level.

21.3 Relationship between carbon market and renewable energy

Essence of relationship between carbon market and renewable energy

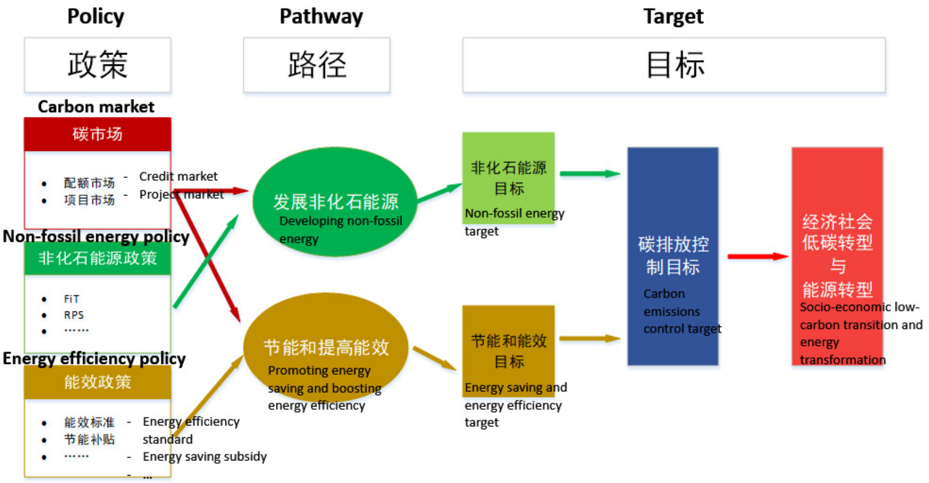
In general, there is no direct connection between carbon markets and renewable energy. Carbon markets aims to reduce carbon emissions of various carbon emitters with relatively low costs and impose direct carbon emissions restrictions on carbon emitters covered within the scope of the market. Renewable energy enterprises, which generate no carbon emissions, are thus not covered by any carbon emissions market. But emitters covered by carbon markets may use renewable energy to lower their carbon emissions, hence forming an indirection connection.

Under the development goal of addressing global climate change and enabling an energy transition, carbon market and renewable energy development constitute a combination of a key policy measure and a basic pathway for decarbonization. Carbon market is a policy measure for realizing established carbon emissions control targets and through introduction of market mechanisms, reducing the whole society's overall cost of realizing such targets. Renewable energy development, on the other hand, may entail multiple policy goals, such as enhancing energy security, fostering relevant industries, promoting ecological and environmental protection and reducing carbon emissions. However, the driving motivation of problems such as air pollution and fossil fuel resource exhaustion will gradually reduce and carbon emissions control mechanisms will increasingly be the policy imperative of an ecological development.

Carbon market plays a role in promoting renewable energy development while at the same time giving impetus to energy conservation and boosting energy efficiency. A rising share of renewable power generation helps to reduce the amount of carbon emissions per unit of power consumption. Under a given carbon emissions limit, final power consumers are more inclined to use low-carbon power sources. In addition, some renewable power generation projects may take advantage of project-based mitigation mechanisms to generate project emissions reduction credits (e.g. CCER), gain carbon market access to fulfilling their emissions reduction obligations as market contractual entities and thus promoting the development of renewable energy. Meanwhile, carbon market is also positioned to incentivize emitters to adopt energy-saving measures for lowering their carbon emissions.

Likewise, renewable energy development has an influence on carbon markets as well. Considering the rapid growth of renewable energy, emitters covered by carbon markets will see their carbon emissions gradually declining due to use of renewable energy. This will affect the supply-demand balance within carbon market, and further drive changes in carbon market transaction prices. If the act of emitters using renewable energy is driven by carbon emission limits, then its influence may already have been internalized within the carbon market action mechanism. Other policies for promoting renewable energy development (e.g. FiT, RPS, etc.) also effect the carbon market operation. Hence, the interplay between them is the mutual effect between carbon market and other renewable energy policies.

Figure 21-6 Diagram of the relationship between carbon market and renewable energy development



The connection between carbon market and renewable energy is in actuality a substantial relationship on the basis of "carbon mitigation" at the level of carbon emitter, e.g. enterprise, organization, etc. Against the backdrop of climate change and energy transition, the relationship between them is one between policy measure and basic pathway. Especially under the requirement of achieving the 2℃ temperature rise limit, carbon emissions control will be a main driver for renewable energy development in the medium and long term. As a result, carbon market and renewable energy will have an increasingly stronger connection in the future. Moreover, carbon markets and renewable energy development have mutual effects on each other. Given the characteristics of current renewable energy development, that is, being mainly policy-driven, the mutual effects between them are intrinsically interactions between carbon market and other renewable energy development policies. This also suggests that in order to better achieve carbon mitigation and other policy goals for renewable energy development, coordination must be further strengthened between carbon market and other policies.

Action mechanisms between carbon market and renewable energy

Carbon market's influence on renewable energy development

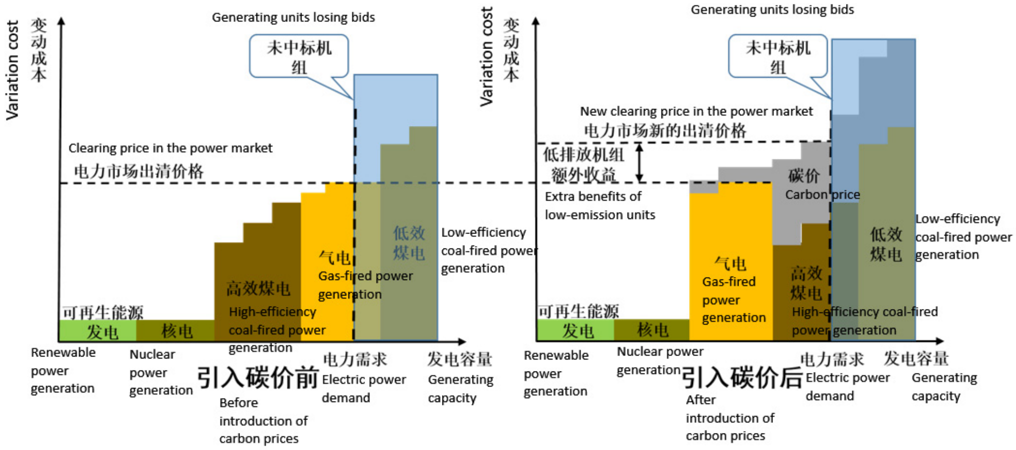
The main ways through which carbon market exerts an influence on renewable energy development, concern the following three aspects:

First, the carbon market increases the costs of fossil fuel utilization and changes the comparative advantages of non-fossil fuels against fossil fuels, hence providing impetus to renewable energy development.

Take the power industry as an example. Quotas being allocated for free or at a price, fossil fuel-based power generation enterprises will see their short-run marginal costs climb after being included in a carbon market, as long as entities have limited ability to impact their future allocations. Considering the huge gaps in emission quantity and mitigation costs among power generation enterprises using different types of energy, sufficiently high carbon market prices may result in significant changes in power generation costs among different types, hence changes the power generation merit order. Theoretically, the interplay between carbon price and economic dispatching may provide potential incentives to renewable-based or other low-emission power generating units. In the EU regions and states of the US where carbon trading is implemented, we find it to be true as well. As carbon cost constitute a part of power generating unit's operating costs, and carbon emissions released by such units are quite different, carbon price may further consolidate low-emission power sources' position in the merit order, and thus provide an incentive to the use of even lower-emission generating units.

The bar chart in the left part of Figure 21-7 is a diagram illustrating the merit order of different types of power generating units within a power system over a span of one hour. As renewable energy incurs no fuel costs, renewable-based power generation normally occupies the first place of the sequence. Energy efficiency of power generating units using coal or natural gas as fuel may be also vastly different, so as their operating costs. Therefore, naturally, the merit order will not be the same. The bar chart in the right part of Figure 5 showcases the changes that take place after introduction of carbon prices. When quota prices rise to certain levels, changes are likely to take place in priority sequence of electric power technology.Pasicko's research revealed that when short-term and long-term marginal costs of EU ETS carbon prices reach 62€/t and 40€/t, respectively, natural gas will be considered a more competitive energy source to generate power than coal. The price levels of this specific analysis naturally depends on the gas and coal prices in Europe at the time, as well as a technology assumptions, however, the principle can be applied generally.

Figure 21-7 Raising carbon prices might change the merit order of power generation.



Second, the offset mechanism of carbon market may provide extra economic incentives for renewable energy projects, thus promoting the development of renewable energy.

Subject to technical and resource conditions, economic benefits of renewable power generation projects have historically fallen short of those of coal-fired projects. Introduction of clean development mechanism and voluntary emissions trading, however, can provide extra income for renewable power generation projects, thus greatly improving their economic viability. For example, according to public announcement of China Clean Development Mechanism Network (sponsored by NDRC Department of Climate Change), out of 3,172 renewable energy projects registered in China, average benchmark yield, excludes CDM, of small hydropower projects (with an installed capacity ≤15MW specified by UNFCCC) is 7.1%, which falls far short of the 10% threshold for small hydropower projects (with an installed capacity ≤25MW in accordance with Chinese regulations) that mandated by Economic Evaluation Code for S**mall** Hydropower Projects (SL16-95); if supported by CDM, benchmark yield of the above-mentioned small hydropower projects raises to 11.3%, which makes them financially viable[132]. China has actively participated in clean development mechanism and voluntary emissions trading for the past decade. Through CER (Certified Emissions Reduction) and Chinese Certified Emission Reduction (CCER) transactions, China has provided robust support to industrial development of wind, solar PV and biomass power generation (Figure 21-8).

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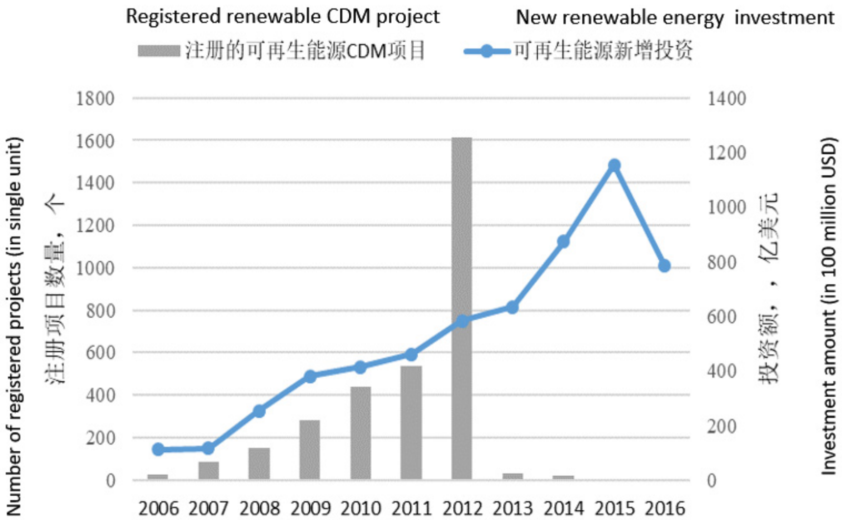
[132] HAN Xilong, et. al. Opportunities and Challenges for Renewable Energy GHG Emissions Trading in China, Ecological Economics, Feb., 2015.

Figure 21-8 Registration number of Chinese CDM projects in the renewable energy category[133] and renewable energy investment value



Third, revenue from carbon credit auctions in a carbon market may be directly used to support renewable energy development.

Credit auction has so far been recognized as a more effective credit allocation method for mature carbon market operation. Some carbon markets, which are currently in operation, have considered or are considering the option of conducting auctions for a certain proportion of their credits. For example, in 2005 when EU ETS was initiated, almost all credits were allocated free of charge. After the second phase of EU ETS was launched in 2008, 3% of all available credits were used for auctions. Since the third phase was launched in 2012, 40% of credits have been issued through auctions, while all credits for the electric power industry are transacted through an auction mechanism. Ever since the US RGGI was launched in 2009, all emissions credits have been transacted through auctions.

Table21-1 Share of free allocation during the third phase of the EU ETS

Share of free allocation	2013	2014	2015	2016	2017	2018	2019	2020
Power sector	0	0	0	0	0	0	0	0
Industrial sector	0.8	0.729	0.657	0.586	0.514	0.442	0.371	0.3
Industrial sector sensitive to carbon prices	1	1	1	1	1	1	1	1

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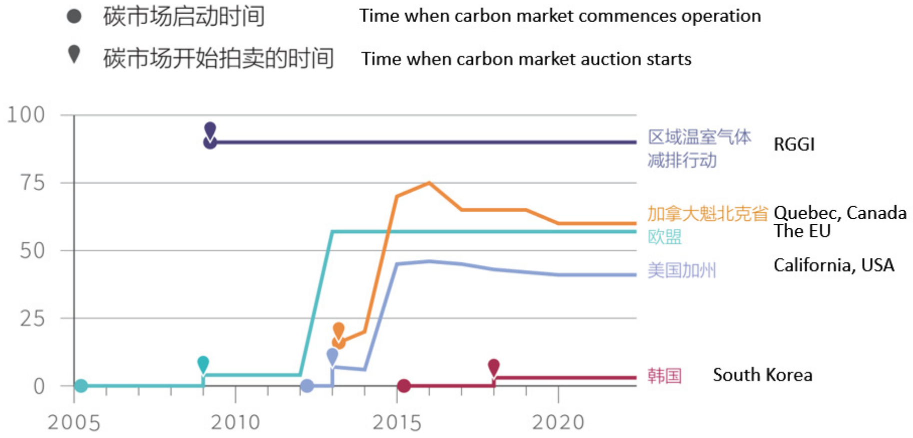
[133] Affected by international climate policies, CDM projects ceased operation after 2012.

Figure 21-9 Shares of credit auctions by carbon markets and auction start time



As of 2015, revenue from carbon credit auctions worldwide was close to US$26 billion. Take the EU as an example: Despite differences in carbon auction shares in each member state, the EU regulations require at least 50% of auction revenue be used to support climate actions. Moreover, the EU sponsored one of the world's largest innovative and low-carbon energy projects: NER 300.By 2014, the Foundation had invested over US$2.4 billion in unripe renewable energy (RES) technologies and carbon capture and storage (CCS) programs. Up until now, it has provided support for 39 key projects. For another example, the US RGGI successfully raised a total of US$1.37 billion from carbon credit auctions during 2008-2014. The auction revenue was mainly dedicated to support energy efficiency and renewable energy investment programs, as well as helping low-income families, with their spending as a percentage of total revenue being 57%, 15% and 15%, respectively, and produced economic and social benefits. RGGI has proven itself to be an excellent example of "recycling" auction revenue from emissions trading back to energy efficiency and renewable energy investment projects.

Figure 21-10 Main support areas and amounts of sales generated from the EU carbon auctions (2013-2015)

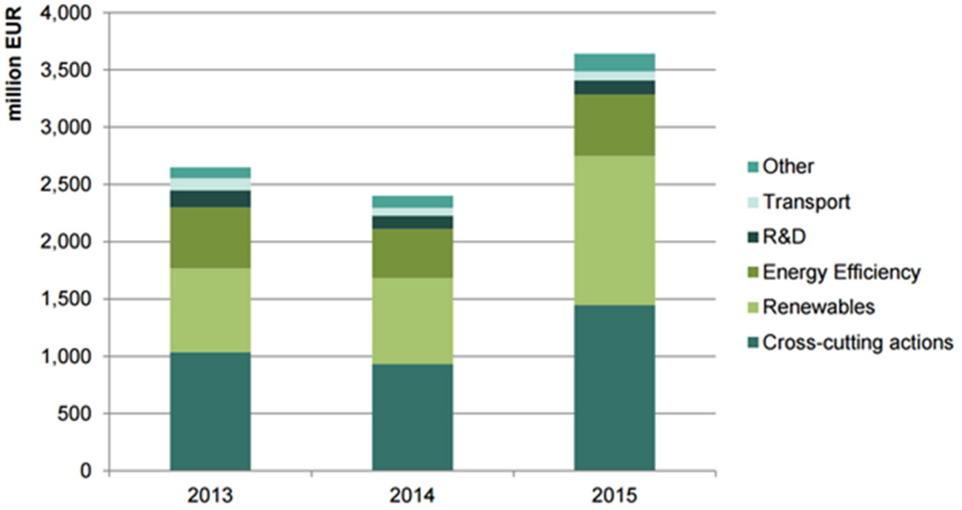


Figure 21-11 Types and number of projects of each member state supported by NER300 Phase III of the EU carbon market

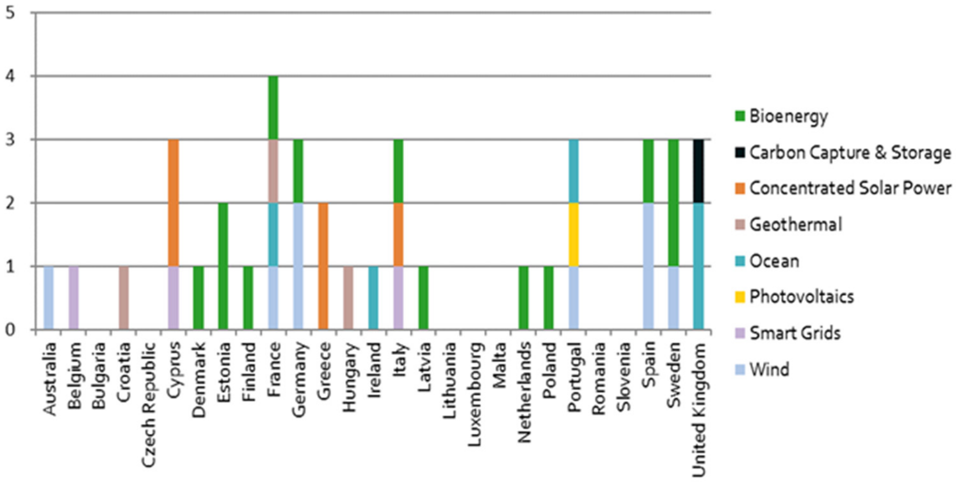


Table 21-2 Results of "recycling" revenue from carbon credit auctions under RGGI

Category	Total (2008-2014)	Total life cycle
Energy efficiency investment evaluation		
CO2 emissions reduced	1.6 Mt	12.9 Mt
Electricity saved	2.2 TWh	16.2 TWh
Energy spending saved	$388 million	$3.62 billion
Renewable energy investment evaluation		
CO2 emissions reduced	112 kt	2.1 Mt
Electricity saved	264 GWh	4.4 TWh
Energy spending saved	$50.1 million	$838 million

To sum up, carbon market exerts an influence on renewable energy development primarily through increasing the costs of fossil fuel utilization and enhancing the comparative advantage. Such an influence is determined mainly by carbon market prices. Even if a renewable energy project gains access to carbon market by way of project emissions credits, the extra monetary incentive it thus obtains is directly correlated with carbon market price. Therefore, the carbon price is a key indicatorillustrating the characteristic influence of carbon market on renewable energy development. To use carbon market revenue in support of renewable energy development depends on the design of carbon market credit allocation system, and is to a large extent affected by political decision-making when it comes to appropriating market revenue.

Renewable energy development's influence on the carbon market

Renewable energy development mainly exerts an influence on carbon market, thorough the two aspects discussed in the following:

First, renewable energy development generates a replacement effect on fossil fuel consumption, thus lowering the actual carbon emission level of emitters covered by a carbon market.

Under the premise of a pre-determined total amount of energy consumption, renewable and fossil energy are mutually replaceable. This is especially true for the electric power industry. In the past, China's power supply always fell short of demand. Many power supply construction projects were launched under the principle of "going all out and going fast". Under these circumstances, direct competition between coal-fired and renewable-based power to win market share was not quite conspicuous. With China's economic development entering a "new normal", growth in power demand is shifting into a lower gear. The lack of timely adjustments to thermal power generation development has created a risk of overcapacity of the industry. As renewable energy absorption becoming a day-to-day bottleneck, competition between the two fighting for power generation share makes it a more and more prominent problem.Judging from carbon market development, both the opening of coal-fired power generation planning and rapid growth of renewable energy have resulted in uncertainties in carbon emissions credit allocation. Particularly in the initial development stage of power spot markets, renewable energies, owing to their lower marginal costs, are almost certain to win power generation shares from fossil fuels. This will make the amount of power generated from fossil fuels lower than expected, thus freeing up carbon emissions credits and consequently declining carbon prices.

China's carbon market design has taken into account both direct and indirect emissions attributed to power generation. Carbon emissions from final emitting units such as cement and electrolytic aluminum plants are also covered within the scope of supervision. Following this thought, renewable power generation exerts its influence on carbon markets in the following two aspects: Firstly, rapid growth of renewable energy causes a significant decline in the power industry's carbon emission factor, hence a significant decline in indirect power-related emissions even in cases where key emitting units take no energy-saving actions. As a result, the mitigation effects attributable to power saving of final users will be reduced. Secondly, popularization of distributed renewable power generation also weakens final emitting units' reliance on public grids, hence resulting in the loosening of carbon market credits.

Second, renewable energy projects gain access to carbon market through emission credits, which increases carbon credit supply in the carbon market.

Using project emission credits within carbon market as an offset mechanism has now become a common practice. Renewable energy projects are usually viewed as high quality sources of project emission credits. Beyond the scope of carbon market coverage, renewable energy projects are favored by the market because of their lower emissions costs. Nevertheless, an oversupply of project emission credits inside a carbon market may cause a supply-demand imbalance, hence affecting carbon market price levels and the corresponding mitigation incentive effects. For example, excessive use of CERs by enterprises during the second phase of the European carbon market might further intensified a supply-demand imbalance against the backdrop of an economic recession, which led to an EU policy shift on the regulations regarding the usage of project emission credits inside the carbon market.

Summary

Carbon market and renewable energy development have a mutual influence on each other. In general, carbon market should exert a promoting influence on renewable energy development. The magnitude of such an influence depends largely on carbon market prices, and whether the allocation mechanisms affect the fossil generators short-run marginal costs. Another potential way carbon market may exert influence is to employ a paid allocation method, like auction, the income of which is used in support of renewable energy development.

Renewable energy development affects the supply-demand balance of carbon market and thus exerts an influence on carbon market prices. Such an influence encompasses the effects of other renewable energy support policies on carbon market. Coordination between renewable energy development policies and carbon market will become an issue worthy of paying close attention to in the future.

21.4 Possible influences of China’s national carbon market on renewable energy development

Price trends of the national carbon market

As mentioned, carbon markets’ influence on renewable energy development is to a large extent determined by carbon market prices.To analyze the influence of China’s national carbon market on renewable energy development, we will first have to look at future price trends of the national carbon market.

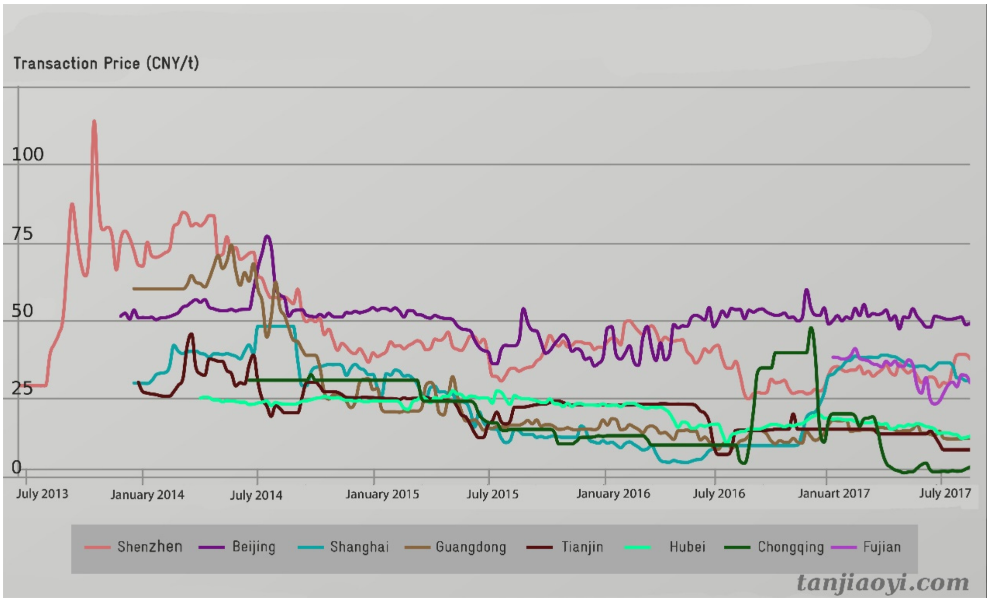
Before 2020

Currently still in a preparatory stage, China’s national carbon market is projected to be initiated in 2017. During the market initiation stage, the main task is to set up a carbon market, keep it running, make participants gradually adapted to carbon market rules and actively take part in it, and strive to maintain transactions of carbon trading market as smoothly as possible. During its initial operation stage, in view of political feasibility, normally a free allocation method will be adopted. Carbon market prices are expected to be low through initially generous allocation, to reduce risks the system may create in the market.

China's carbon trading pilot projects, 7 pilot projects, located separately in Beijing, Tianjin, Shanghai, Chongqing, Guangdong, Hubei and Shenzhen, allocate 1.2 billion tons of carbon emission credits per year to over 2,000 enterprises in more than 20 industries. As of the end of December 2015, these markets generally maintained smooth operations, with a total transaction volume of approx. 50 million tCO2 worth approx. 1.34 billion yuan, at an average transaction price of nearly 27 yuan/tCO2.

China’s national carbon trading market will be formed based on the experience obtained from these 7 carbon trading pilot projects. During the initial stage, the market’s constraining power on carbon emissions might be very limited. Therefore, the expected market price will basically stay at a level close to the 7 carbon trading pilots, i.e. in the range of 30-50 yuan/tCO2.

Figure 21-12 Carbon price trends of China's 7 carbon trading pilots



2020-2030

With the rules and operation of the national carbon market being gradually on track during 2020-2030, carbon market is expected to play a vital role in facilitating the country to achieve the goal of peaking in carbon emissions by 2030. In this process we assume that the allocation principles will be adjusted, to ensure that carbon prices bleed thorough to short-run marginal generation costs in the power sector. Prior to 2030, however, to realize the goal of peaking as early as possible, control over carbon emissions is likely to be gradually strengthened, hence is expected to drive the prices higher.

To support the goal of limiting the average global temperature rise to below 2 degrees Celsius, the carbon price must be in a range that is rational to motivate the power industry be the first to realize low-carbon energy transition. Given constant declines in LCOEs of renewable energies, the carbon price range needs to be renewed regularly in the future. The IEA report (2017)[134] suggests by 2050, over 95% of the world's electricity will be generated from low-carbon energy sources. For OECD countries, carbon prices of 2020, 2025 and 2030 are expected to reach US$20, 65 and 120, respectively; for main developing countries (including China), carbon prices of 2020, 2025 and 2030 are expected to reach US$10, 45 and 90, respectively; for other regions, carbon prices of 2020, 2025 and 2030 are expected to reach US$5, 10 and 25, respectively.IEA ETP 2015 reveals that under the 2℃ scenario, future global average carbon prices will fall into the following ranges: Year 2020 – US$30-50; Year 2025 – US$50-70; and Year 2030 – US$70-90. In its 2017 report, Carbon

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[134] IEA 2017. Perspectives for the energy transition: investment needs for a low carbon energy system.

Tracker states that the corresponding carbon prices mainly based on INDCs submitted by different countries are: US$30 (2020), US$30 (2025) and US$40 (2030). But according to a UNEP report, mitigation efforts suggested by INDCs of different countries are still a far cry from the emissions pathway for holding the rise of global average temperature to below 2 degrees Celsius. According to CDP's 2017 report, the corresponding carbon price ranges based on suggestions of global industrial and enterprise representatives and experts are: Year 2020 – US$24-39; Year 2025 – US$30-60; and Year 2030 – US$30-100.

Table 21-3 The prediction of carbon prices from different agencies($/ton)

		2020	2025	2030
IEA(2015)	2℃Scenario	30~50	50~70	70~90
IEA(2017)	OECD	20	65	120
	Major Developing Countries	10	45	90
	Other Countries	5	10	25
Carbon Tracker(2017)	INDCScenario	30	30	40
CDP(2017)		24~39	30~60	30~100

Based on the above considerations and international organization projections, assuming national carbon market prices rise gradually during 2020-2030, then by 2030, carbon prices are expected to reach the level of at least 100-200 yuan/tCO_2, to be an effective motivation for decarbonization. Carbon market has a broad influence; in the meantime, carbon market prices are affected by multiple factors. At the supply-demand level, influencing factors mainly include market system design, enterprise production and operation behaviors, and emissions reduction technology; at macro level, carbon market prices are greatly affected by economic situation, energy market price and financial market; furthermore, other factors, such as climatic events, may also lead to market price fluctuations. Hence, there are huge uncertainties when it comes to making predictions on future carbon market prices, however these considerations underpin the core assumptions of the scenarios introduced in Part 2 of this report.

Table 21-4 Assumed minimum price of emitting CO2 in the two scenarios(RMB/ton)

	2017	2020	2030	2040	2050
Stated Policies	30	50	100	100	100
Below 2 degrees	30	50	100	200	200

Possible influences of national carbon market on renewable energy

Before 2020

Carbon market exerts influence on renewable energy mainly by increasing the costs of fossil fuel power generation and changing the comparative advantages of renewable energy against fossil fuels in power generation. Hence, our quantitative analysis of the national carbon market before 2020 will be mainly focused on its overall influence on coal-fired power plant operating costs during its initial stage, and on that basis, determine its potential influence on renewable energy.

(1) Credit allocation method

For the power industry, carbon emission credits are allocated in a benchmarking method, under which the 2015 output is used as a benchmark, and 70% of credits allocated as initial credits. Actual credits will be later determined, subject to final accounting after actual output is known. According to present policy design, emission credits are allocated to power enterprises free of charge using a benchmarking method. Considering the huge gap in energy efficiency levels and carbon emission amounts among different types of generating units, generating units are divided into 11 categories by type and capacity as follows.

Table 21-5 Baseline classification criteria for the power industry

No.	Classification Criteria	Credit Baseline (tCO2/MWh)
1	1,000MW ultra-supercritical unit	0.8066
2	600MW ultra-supercritical unit	0.8267
3	600MW supercritical unit	0.8610
4	600MW subcritical unit	0.8928
5	300MW supercritical unit	0.8748
6	300MW subcritical unit	0.9266
7	CFBC IGCC unit with a capacity of 300MW or above	0.9565
8	High ultrahigh pressure unit with a capacity of 300MW or below	1.0177
9	CFBC IGCC unit with a capacity of 300MW or below	1.1597
10	Gas unit in F grade or above	0.3795
11	Gas unit below F grade	0.5192

Based on the given baseline, the credit allocation scheme is as follows:

Total amount of credits for allocation = total power supply credits + total heat supply credits
Total power supply credits = power supply amount X emission baseline X cooling type correction coefficient
X heat supply amount correction coefficient X fuel value correction coefficient
Total heat supply credits = heat supply amount X heat supply baseline

Regarding the calculation of total power supply credits, heat supply correction coefficient of coal-fired power plant is 1-0.25× heat supply ratio, and that of gas-fired power plant is 1-0.6× heat supply ratio; cooling-type correction coefficients are 1 and 1.05, respectively for water-cooling and air-cooling; fuel heat value correction coefficient only exists with laboratory fluid bed dryer IGCC generating units. For other generating units, default value can be either set as 1 or considered to be non-existent. For laboratory fluid bed dryer and IGCC generating units, correction coefficients are 1.03 and 1, respectively, in cases where heat value is lower than 3,000 Kcal and higher than 3,000 Kcal. Regarding the calculation of total heat supply credits, heat supply baseline for all coal-fired power generating units is 0.1118t CO_2/GJ; and that for all gas-fired units is 0.0602t CO_2/GJ.

(2) Influence on overall operating costs of the coal power industry

According to CEC (China Electricity Council) data, as of the end of 2015, total installed capacity of coal-fired generating units with a 6,000 kW or above capacity, which were covered within the scope of the power industry statistical survey, reached 97,033 MW, accounting for 97.00% of China's total installed capacity of coal-fired power generating units with a 6,000 kW or above capacity. The share of installed capacity of coal-fired power generating units with a 600 MW capacity or above was 42.91%, an increase of 1.4 percentage point year over year, whilst the share of installed capacity of coal-fired power generating units in other capacity grades witnessed a decrease year over year.

Table 21-6 Grade structure of installed coal-fired power generating capacity within the scope of 2015national statistical survey

Index classification	Number of units	Total installed capacity (MW)	Share in installed coal-fired power generating capacity covered within the scope of survey
Units with a 6,000 kW capacity or above	7526	970330	100
Unit capacity≥100	86	86700	8.93
600≤Unit capacity＜1000	523	329680	33.98
300≤Unit capacity＜600	1051	346000	35.66
200≤Unit capacity＜3000	254	54880	5.66
100≤Unit capacity＜200	467	64030	6.60
6≤Unit capacity＜100	5145	89040	9.18

In 2015, utilization hours of coal-fired power generating units in various capacity grades all declined to varying degrees. Of them, declines in utilization hours of units with a 200-1000 MW capacity are moderate, ranging between 200-400 hours; utilization hour decline of units with a 100-200 MW capacity are the greatest, reaching up to 1,082 hours; and utilization hour declines of units with a 6-100 MW capacity were the slightest, being only 17 hours. Such units mostly use residual heat/pressure, biomass or garbage for power generation, hence having relatively higher utilization efficiency.

Table21-7 Standard net coal consumption rate of coal-fired power generating units of different capacity grades in large-scale power generation enterprises in 2015

Capacity grade (MW)	Number of units	Total installed capacity (MW)	Average net coal consumption rate (gce/kWh)	Utilization hours
All units	1912	707060	306	4364
Unit capacity≥1000	82	82610	287	4872
600≤Unit capacity＜1000	454	287110	309	4393
300≤Unit capacity＜600	803	265890	305	4128

200≤Unit capacity＜300	175	36710	324	3884
100≤Unit capacity＜200	207	28980	327	3727
6≤Unit capacity＜100	191	5750	355	4291

Table 21-8 Energy efficiency benchmarking of coal-fired power generating units in 2015

Classification Criteria	Number of units	Cooling type	Average net coal consumption rate (gce/kWh)
1,000MW ultra-supercritical unit	55	Wet cooling	284.77
	2	Air cooling	298.07
600MW ultra-supercritical unit	57	Wet cooling	286.45
600MW supercritical unit	144	Wet cooling	301.35
	42	Air cooling	315.39
600MW sub-critical unit	82	Wet cooling	314.64
	47	Air cooling	329.93

Based on existing data, we may calculate the average baseline of the electric power industry, using the utilization hours of large-scale power generation groups' power generating units in different capacity grades, in combination with energy efficiency benchmarking results of coal-fired generating units. As CFB and IGCC units take up very small shares, they are excluded from further discussion. Table 21-9 shows an energy allocation structure.

Table21-9 Energy structure of different types of power generating units

No.	Classification Criteria	Credit Baseline (tCO_2/MWh)	Energy share
1	1,000MW ultra-supercritical unit	0.8066	9.98%
2	600MW ultra-supercritical unit	0.8267	5.24%
3	600MW supercritical wet cooling unit	0.861	13.24%
	600MW supercritical air cooling unit	0.90405	3.86%
4	600MW subcritical wet cooling unit	0.8928	7.54%
	600MW subcritical air cooling unit	0.93744	4.32%
5	300MW supercritical unit	0.8748	20.24%
6	300MW subcritical unit	0.9266	13.49%
7	High ultrahigh pressure unit with a capacity of 300MW or below	1.0177	19.69%

Hence, based on weighted calculation, we conclude that the average baseline of the coal power industry is 0.883t CO2/MWh. In 2015, China's carbon emission rate for power supply of coal-fired generating units was approx. 0.9133t CO2/MWh. In consideration of the carbon market initiation time, the rate is expected to drop to 0.8989t CO2/MWh in 2017 based on the past improved rate, which is 0.0159t CO2/MWh short from the average baseline of the coal power industry. If contribution from enhanced energy efficiency reaches 0.0057t CO2/MWh in 2018, then there will only be a 0.0101t CO2/MWh gap to be made up with credit transactions. Therefore, it can be determined that although the current baseline for the coal power industry is overall a little bit stringent, its gap with the actual level of the power industry is not very big.

Considering carbon prices are expected to fluctuate in the 30~50 yuan/tCO2 range during the initial stage of carbon market, extra cost to be borne by the coal power industry is expected to remain between 0.31~0.51 yuan/MWh, which accounts for less than 0.2% of the average on-grid tariff of the coal power industry. Overall, its impact on the coal power industry is negligible. If the final allocation mechanism is dynamic, it may even increase the profitability of the coal power industry, but most likely only in the short-run.

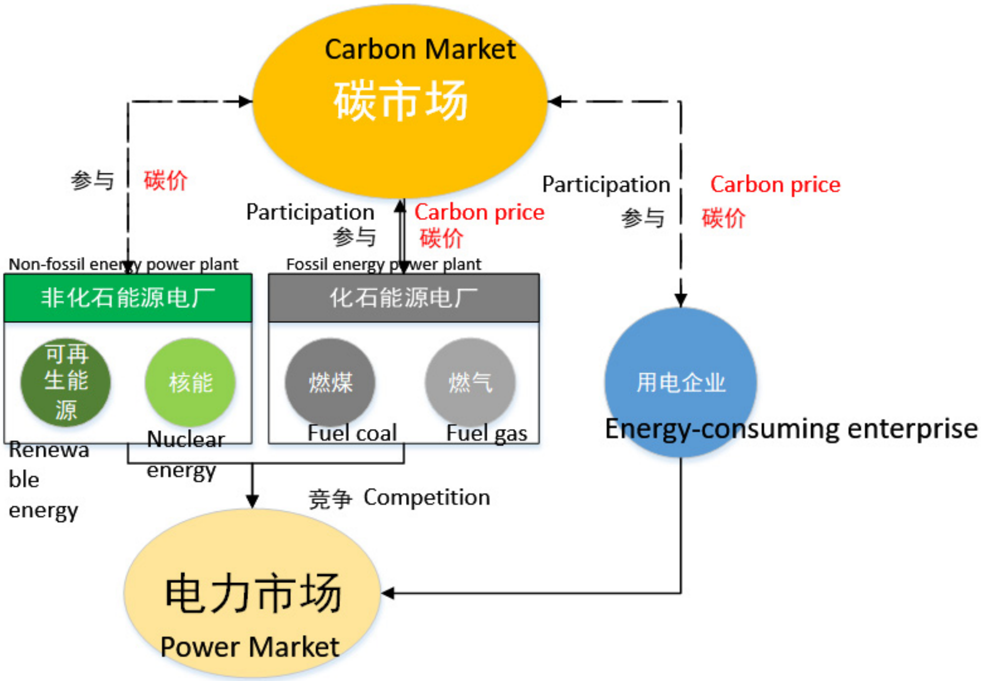
(3) Influence on renewable energy

Based on the above quantitative analysis, if we do not consider the situation of renewable energy gaining access to the national carbon market through project emission credits, and consider only the extra operating costs that the carbon market added to coal-fired power plants, then renewable energy development will hardly receive any impetus from the national carbon market in 2020 when it is initiated. Furthermore, we assume the allocation principles are adjusted such that the carbon market price affects the marginal generation costs of fossil generators.

2020-2030

Before 2020, to compare cost variations among coal-fired power plants is to compare them under the circumstances of with carbon trading and no carbon trading, and to analyze extra costs incurred from carbon trading. During 2020-2030, with enterprises obtaining more and more knowledge about carbon market operation, carbon emission credits will become their carbon assets, and carbon assets management will turn into specialized business as carbon market gradually develops. Hence, to analyze carbon market's influence on renewable energy power plants, we will first compare the LCOEs between new thermal and renewable energy power plants, and then determine the carbon price demand when the two are in balance; on the other hand, given the current reality of overcapacity in the coal power industry, we will assume a price-bidding scenario for typical coal-fired and new renewable energy power plants in the power market, in order to determine the carbon price demand when the two are in a balance.

Figure 21-13 Diagram of carbon market's influence on power plant operation



(1) LCOE of new power plant investment at break-even carbon price

Currently, in comparison with coal-fired power generation, renewable power generation is in a disadvantageous position in terms of cost per kilowatt hour of the electricity generated. An LCOE analysis may help us understand the carbon price demands of new coal-fired and renewable energy power plants when a break-even point is reached in cost competition. Through such comparison, an enterprise will be able to determine the appropriate carbon price level should it decide to build a new power plant.

To that end, we select three time points, i.e. 2020, 2025 and 2030, and taken not only the influence of rises in resources and environment costs (e.g. coal price, water price, and pollutant emission expense, etc.) on coal-fired power generation into account, but also the promoting effects of technological advances on reducing investment costs of wind and solar PV power generation. Analysis results indicate:

Table 21-10 Investment costs assumptions in wind and solar power (Million RMB/ton)

	2020	2025	2030
Wind power, onshore	7,5	7,2	6,8
Solar power, utility scale	4,8	4,5	4,2

In 2020, if it is merely owing to carbon prices that the costs per kWh of electricity for new wind and thermal power generation stay basically at the same level, then carbon price demand will remain at relatively high levels. With that the demand carbon price for wind and solar PV power will be in the range of 130-320 and 420~510 yuan/t, respectively. But if carbon prices during the period are unable to reach such high levels, then it is unlikely that price relations between renewable and coal-fired power will be altered solely by the carbon price.

In 2025, carbon price demands for wind and solar PV power generation are expected to decline significantly. Carbon price of wind power will drop to 0-180 yuan/t. In Guangdong where coal-fired power generation cost is high, reversion of power generation costs has already taken place between renewable and coal-fired power. Introducing carbon prices will give renewable energies further competitive advantages; in Jiangsu and Inner Mongolia, carbon price demand is expected to drop to less than 100 yuan/t. Such a carbon price level will be relatively easy to achieve even after carbon market construction steps into a new stage. Carbon price demand for solar PV power is expected to drop to 145-280 yuan/t. The cost gap between solar PV and coal-fired power generation will further decrease because of the carbon market.

In 2030, carbon price demands for wind and solar PV power generation are expected tostep into relatively low levels, with that for wind and solar PV power dropping to 0-75 and 0-125 yuan/t, respectively. The Carbon market's establishment is will help renewable energy attain a leading position against coal in terms of power generation cost.

Table 21-11 Carbon price required to attain LCOE parity with coal power (yuan/tCO2) in 2020

	New wind power	New solar PV power
Guangdong	130	420
Jiangsu	225	495
Inner Mongolia	240	470
Xinjiang	320	510

Table 21-12 Carbon price required to attain LCOE parity with coal power (yuan/tCO2) in 2025

	New wind power	New solar PV power
Guangdong	-	145
Jiangsu	80	240
Inner Mongolia	100	240
Xinjiang	180	280

Table 21-13 Carbon price demands (yuan/tCO2) in 2030

	New wind power	New solar PV power
Guangdong	-	-
Jiangsu	-	50
Inner Mongolia	5	85
Xinjiang	75	125

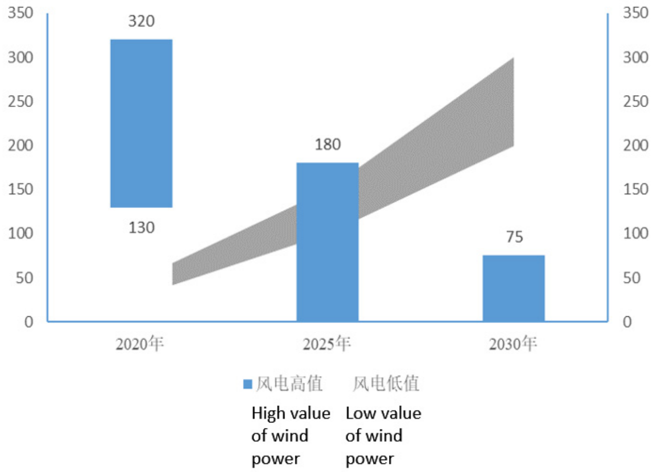
Based on carbon market price trends we discussed in the previous section, after comparing carbon prices at the same LCOE of investment in new wind/solar PV and coal-fired power plants, we discover that:

(1) Overall, the carbon prices required for the same LCOE investment have demonstrated a rapidly declining trend;

(2) In 2025, carbon market prices are expected to reach at 100-150 yuan, at levels exceeding the carbon price demand for a break-even level of wind power generation in Guangdong, Jiangsu and Inner Mongolia. They are close to the break-even level of solar PV power generation in Guangdong as well. This indicates that by 2025, the carbon market is expected to have an influence on enterprises' decision making regarding invest in coal-fired and wind/solar PV power plants in some regions.

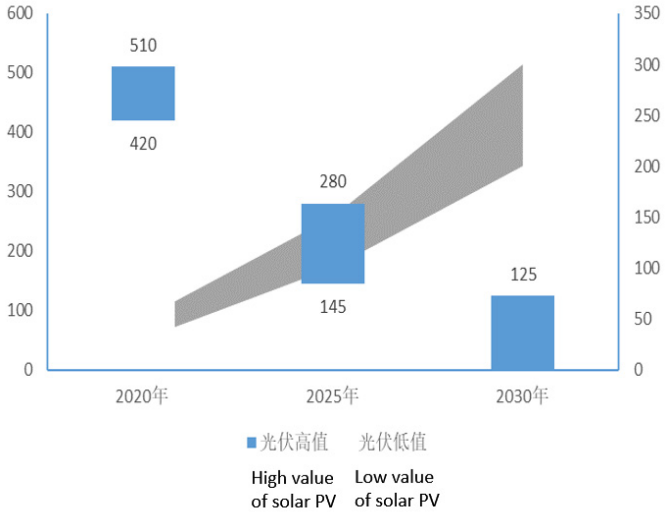
(3) In 2030, carbon market prices are expected to reach 200-300 yuan, exceeding the carbon price demands at the LCOEs of wind and solar PV power generation in all regions. Hence, compared to coal-fired power plants, investment in wind and solar PV power plants in the above regions will prove itself to be a better decision.

Figure 21-14 Carbon prices of new wind and coal-fired power plants at the same LCOE



Note: grey area denotes an anticipated range of carbon market prices, assuming carbon prices were the single mechanism to support RE development.

Figure21-14Carbon prices of new solar PV and coal-fired power plants at the same LCOE

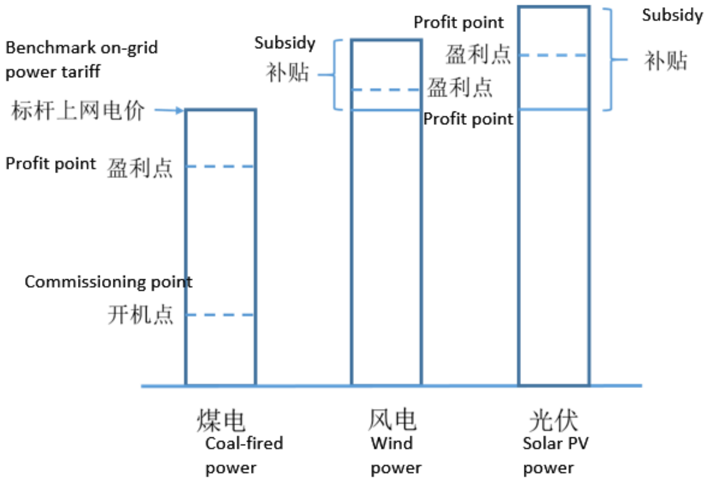


Note: grey area denotes an anticipated range of carbon market prices, assuming carbon prices were the single mechanism to support RE development.

(2) Equilibrium carbon price between typical coal-fired and renewable energy power plants as a result of cost bidding

Due to the current situation of coal-fired power overcapacity in China, output coal-fired units will be mainly composed of existing ones in the future. Renewable energy power plants will largely compete with existing coal-fired power plants in the future. As Figure 21-15 indicates, excepting the subsidized part, wind power and PV power generation shall reasonably design their bidding strategies based on the cost of coal power in the medium and long-term market in addition to the spot market. For coal-fired power units, it needs to ensure the transaction price remains above the "profit point" in the medium and long term market, while in the spot market, it is sufficient to ensure the quoted price above the "commissioning point". It shows that the quoted price of renewable energy shall match that at the "profit point" of coal power in the medium and long term market and that at the "commissioning point" of coal power in the spot market. Under the market mechanism of uniform clearing pricing, the quoted price can be set to zero and the market clearing price shall be decided by coal power. The introduction of carbon price will directly affect the "profit point" and the "commissioning point" of coal-fired units. If carbon emission permits are issued free of charge, considering the proportional relationship of the electric between the medium and long-term market and the spot market, its effects to the "profit point" may be considered negligible while the "commissioning point" will float upward under the influence of the carbon emission cost. If the permits are released through auction bidding, it will lead the "profit point" and the "commissioning point" to move in an increasing trend.

Figure 21-15 Price relationship between coal-fired power and renewable energy



As coal-fired units at or above 600 MV currently account for almost 50% of all coal-fired units in China, and a majority of new coal-fired units at or above 300 MV are constructed after 2005, hence comparisons are made between units of 600 MV and new constructed wind power and PV units, setting 2008 as the average starting year for construction of coal-fired units, 2023 as the year for complete repayment of capital and interest, to compete with renewable energy units directly in the electricity market. Influences of the market price of carbon emission on the development of renewable energy resources are analyzed at respective points in time of 2020, 2025 and 2030.

Comparison of competition strategies between coal-fired power generation and wind power and PV power generation based on the price trend in the carbon market indicates that:

The carbon price that can tie the complex cost of coal power with that of renewable energy power generation will remain at a relatively high level in 2020, 125 yuan/ton for wind power in carbon price and 230 yuan per ton for PV. While the current carbon price can hardly reach such a high level, it may greatly affect renewable energy sources if measures such as cancellation of wind power, benchmarking price for PV power generation and introduction of market competition are taken.

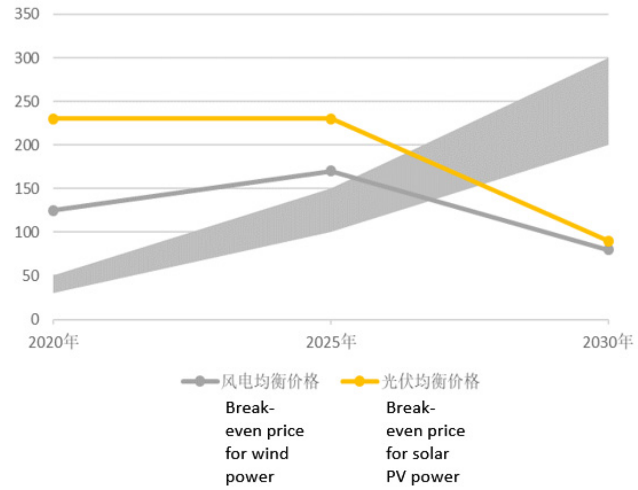
In 2025, repayment of capital and interest will be fully completed for almost all current coal-fired units. “Profit point” starts to go down and “commissioning point” to go up until the two points finally overlap with each other. Therefore, coal-fired units may compete with existing or new renewable energy units without any burden. Under such stringent conditions, carbon price for new wind power will bounce to 170 yuan per ton while it remains at 230 yuan per ton for solar PV. The carbon price will not easily reach this level; nevertheless, it will become an importance force to support the renewable energy sources to compete with coal power.

In 2030, influenced by fuel costs, “profit point” and “commissioning point” will move upward. The carbon price of new wind and solar PV power will decrease to 80 yuan per ton and 90 yuan per ton respectively. This level of carbon price is relatively easy to reach, while wind power and PV power generation will have stronger competitive advantage than coal power at this price level.

Table 21-14Demanded carbon price under a cost bidding mode in the power market (yuan/tCO2)

	New wind power	New solar PV power
2020	125	230
2025	170	230
2030	80	90

Figure 21-16 Price competition between coal energy and renewable energy in the carbon market



Note: Grey area denotes price range of carbon market.

Conclusion

Based on the above analysis, at the initiating stage of the national carbon market before 2020, due to the expected relatively low price level in the carbon market in the range of 30 to 50 yuan/tCO2 and loose selection of baseline of various kinds of coal units, the overall performance cost of the coal power industry may be converted into electricity price at 0.31 to 0.51 yuan/MWh, accounting for less than 0.2% of the total cost of the coal power industry, notwithstanding the possible feedback from carbon prices on power prices and the implication of dynamic allocation mechanisms. Without regard to the effects of project emission reduction scheme, the carbon market influences on the development of renewable energy mainly through approaches such as increase of the cost of coal power and change the comparative advantages of coal power and renewable energy power generation accordingly. Furthermore, the credit allocation mechanism will limit the bleed through of carbon costs to fossil generators marginal costs, in the short-run. Therefore, the national carbon market has relatively limited positive impact on the development of renewable energy sources, in the short term.

During 2020-2030, results of comparison between LCOEs of new power plant investments reveal: considering continuous declines in renewable power generation technology costs in the future, when carbon price touches the ranges of 130-320, 0-180 and 0-75 yuan/tCO2, respectively, in 2020, 2025 and 2030, onshore wind and coal-fired power plants will reach an equilibrium point in terms of cost; when carbon price touches the ranges of 420-510, 145-280 and 0-125 yuan/tCO2, respectively, in 2020, 2025 and 2030, solar PV power generation and coal-fired power plants will reach an equilibrium point in terms of cost. Analysis of China's future carbon market price suggests carbon price is expected to reach 100-150 and 200-300 yuan/tCO2, respectively, by 2025 and 2030. Based on such projections on carbon market prices, by 2025, carbon prices will reach levels that enough to change the decision making on whether investment is to be made in onshore wind or coal-fired power plant. Similarly, by 2030, carbon prices will reach levels enough to change decisions on investment in solar PV or coal-fired power plant. In other words, other support policies for wind energy may all exit by 2025, and those for solar PV energy may fully exit by 2030. Instead, they may all be replaced by the incentive provided by carbon market prices.

Considering the present coal power overcapacity, new renewable energy (e.g. wind, solar PV, etc.) needs to compete with existing coal power capacity in the future. Correspondingly, carbon prices in relation to same-cost overall power generation will be 125 yuan/t, 170 yuan/t and 80 yuan/t, respectively, for wind power, and 230 yuan/t, 230 yuan/t and 90 yuan/t, respectively, for solar PV, in 2020, 2025 and 2030. In comparison with carbon market price levels in the period between 2020-2030, by around 2025, carbon market may provide adequate incentive for new wind power projects in competition with existing coal-fired power generating units; and by around 2030, driven by carbon market prices, new solar PV projects will have stronger competitive power in the market compared with existing coal-fired power generating units.

21.5 Main conclusions

On the relationship between carbon market and renewable energy development

In the context of global climate change and energy transition, the relationship between carbon market and renewable energy development is viewed as one between policy measure and basic pathway. Under the influence of carbon markets, carbon emitters will take a combination of measures, i.e. saving energy, boosting energy efficiency and developing renewable energy, etc., to reduce their emission levels. Hence, a carbon market has a promoting influence on renewable energy development. Renewable energy development bears multiple policy goals, such as enhancing energy security, promoting ecological and environmental protection, strengthening emerging industries, and lowering carbon emissions, amongst others. To limit the rise of global average temperature below 2 degrees Celsius, and enabling a global energy transition towards a low-carbon society, renewable energy development will be playing a more and more prominent role. In the future, promoting the development of renewable energy will be increasingly dependent on carbon emissions control. The relationship between carbon market and renewable energy development, therefore, will be further strengthened with the strengthening of carbon emissions control.

Likewise, renewable energy development also exerts an influence on carbon market. Driven by targets such as energy security, atmospheric environment protection and emerging industry development, renewable energy development itself is to a large extent motivated by support policies. As renewable energy technological costs are still at a high level, renewable energy development are highly policy-dependent. Renewable energy development has an effect on the supply-demand balance of carbon market, resulting in changes in carbon market prices and to a certain degree weakening the positive effects of carbon market on promoting mitigation. The counteractive effect of renewable energy on carbon market is the interplay between support policies for renewable energy (e.g. FiT) and carbon market. In design of relevant policies, it is of vital importance that harmonization among different policies be fully considered.

On the interaction mechanism between carbon market and renewable energy

Carbon markets exertinfluence on renewable energy development mainly in the following three ways: (1) carbon markets increase the costs of fossil energy consumption, hence changing the comparative advantages between renewable and fossil energy; (2) by enabling renewable energy projects to generate emission credits, carbon market provides direct incentives for the development of renewable energy; and (3) revenue from carbon market is used to provide support for renewable energy project funding, technological research and development and related infrastructure construction, which promotes the development of renewable energy. A key indicator of carbon market's influence on renewable energy development is carbon market price. The fact that a relatively high level of carbon market price is beneficial to renewable energy development has been validated by the EU carbon market. Spending carbon market revenue in support of renewable energy development entails adjustment of credit allocation methods and political support bolstering the direction of revenue uses. From a mid- to long-term perspective, with renewable energy growing bigger and bigger in size and costs of renewable power generation continuously declining, subsidy policy will sooner or later complete its historical mission and gradually phase out in an orderly manner. In the post-subsidy era, all sorts of power sources will compete primarily on power generation cost. A continuously-perfected carbon market will become a key driver for changing the comparative advantages and competition landscape of coal-fired and renewable power generation.

Renewable energy exerts its influence on the carbon market mainly in the following two ways: (1) renewable energy replaces fossil fuels, or lowers the carbon emission factor of final power consumption and the actual carbon emission level of contractual entities inside a carbon market, thus changing the market's supply-demand balance; and (2) renewable energy projects have direct influence on the supply-demand balance of carbon market through project emission credits. Renewable energy development affects the supply-demand balance of carbon market and thus exerts an influence on carbon market prices. Such an influence embodies effects of other renewable energy support policies on carbon market. Coordination between renewable energy development policies and carbon market will become an issue worthy to pay close attention to in the future.

As the costs of renewable energy technologies are currently still at relatively high levels, to rely solely on carbon prices for market regulation effects will be hardly enough in the short run to solve the problems facing renewable energy development, such as funding, technology, etc. During the initial period of carbon market, it is proper to consider introducing a certified voluntary emission reduction mechanism at an appropriate time, giving precedence to adoption of renewable power generation technologies (e.g. offshore wind, solar thermal electric power generation, amongst others, technologies with relatively high costs and in an early stage of application), and granting them with direct funding support; as carbon market gradually develops, the electric power industry may be the first to introduce a mechanism of credit auction. A certain proportion of the revenue from credit auctions will be used to support related technological research and development, as well as basic infrastructure construction, of renewable energy development projects.

On national carbon market’s influence on renewable energy development

China is still in the preparatory stage for setting up a nationwide carbon market. Maintaining relatively high carbon price levels will not be politically feasible especially in the initial period when such a market is formed. Average carbon prices of 7 national carbon trading pilot programs suggest future carbon prices to stay in the range of approx. 30-50 yuan/t averagely in the initial period of a national carbon market. At such price levels, coal-fired power generation enterprises’ average carbon mitigation cost in the national carbon market is converted to approx. 0.31-0.51 yuan/MWh, which only accounts for 0.2% of the coal power industry’s average on-grid tariff. It only has a small influence on coal-fired power plant operation. Therefore, its promoting effect on renewable energy development is very limited.

As renewable power generation (wind, solar PV, etc.) costs gradually decline in the future, LCOE of new wind and solar PV power systems are to keep up with the cost of new thermal power plants. Correspondingly, required carbon market prices of wind generation in different regions will be 130-320 yuan/t, 0-180 yuan/t and 0-75 yuan/t, respectively, and those of solar PV power generation in different regions 420-510 yuan/t, 145-280 yuan/t and 0-125 yuan/t, respectively, in 2020, 2025 and 2030. Considering the present coal power overcapacity, new renewable energy (e.g. wind, solar PV, etc.) needs to compete with existing coal power capacity in the future. Correspondingly, carbon prices in relation to same-cost overall power generation will be 125 yuan/t, 170 yuan/t and 80 yuan/t, respectively, for wind power, and 230 yuan/t, 230 yuan/t and 90 yuan/t, respectively, for solar PV, in 2020, 2025 and 2030. Based on relevant organizations’ projection on future carbon market prices, by 2030, China’s carbon market prices are likely to reach at a level of 200-300 yuan/tCO2. It can be expected that, with the gradual development and perfection of the carbon market, as well as increasingly intensified carbon emissions control targets and continuously declining renewable energy technological costs, carbon market is likely to replace renewable energy subsidy as an important driver for renewable energy development.

Part 4:
Case Study: Beijing-Tianjin-Hebei Region

22 Case Study: Beijing-Tianjin-Hebei Region

22.1 Economic Development in Beijing-Tianjin-Hebei Region

Located at the heartland of Bohai Rim as the national "capital region" of China, the Beijing-Tianjin-Hebei Region (as known as Jingjinji Metropolitan Region, JJJ in short) represents one of the largest economic and most dynamic regions in Northern China, including Beijing, Tianjin and 11 prefecture-level cities of Hebei Province, namely Shijiazhuang, Tangshan, Langfang, Baoding, Qinhuangdao, Zhangjiakou, Chengde, Cangzhou, Handan, Xingtai and Hengshui, with more than 100 million population and an area of approximately 216,000 sq.km. Chinese government has proposed the national strategy of integrated development of Beijing, Tianjin, and Hebei Province in February 2014, aiming at creating a new capital economic region that can efficiently utilize different advantages of these provinces (cities), which may promote the sustainable development of Bohai Economic Rim and further drive the joint development of northern hinterland of China. The focus shall be on the following aspects: facilitating innovations of regional development system and mechanisms; improving the layout and morphology of metropolitan areas and providing demonstrative examples for optimizing the regional layout; discovering an effective pathway of ecological civilization construction that can better coordinate the development of population, economy, resource and environment.

Evaluation of Economic Development

Beijing

In 2016, under the internationally and nationally complicated situation, Beijing kept generally steady economic operation, continuously promoted structural adjustment, accelerated the accumulation of new economical kinetic energy, and steadily improved development quality. In 2016, Beijing realized regional GDP of CNY 2.48993 trillion, increasing by 6.7%, with growth rate drop of 0.2% over previous year calculated at comparable prices. From the perspective of industries, the value-added of primary industry was CNY 12.96 billion, decreased by 8.8%, with the growth rate rise of 0.8% compared with the same period of last year; the value-added of secondary industry was CNY 477.44 billion, increased by 5.6%, with the growth rate rise of 2.3%; and the value-added of tertiary industry was CNY 1.99953 trillion, increased by 7.1%, with the growth rate drop of 1%. The structural proportion of primary, secondary and tertiary industries was changed from 0.6:19.6:79.8 in last year to 0.5:19.2:80.3, with the rise in the proportion of tertiary industry.

Figure 22-1 GDP and Growth Rate of Beijing during 2011-2016

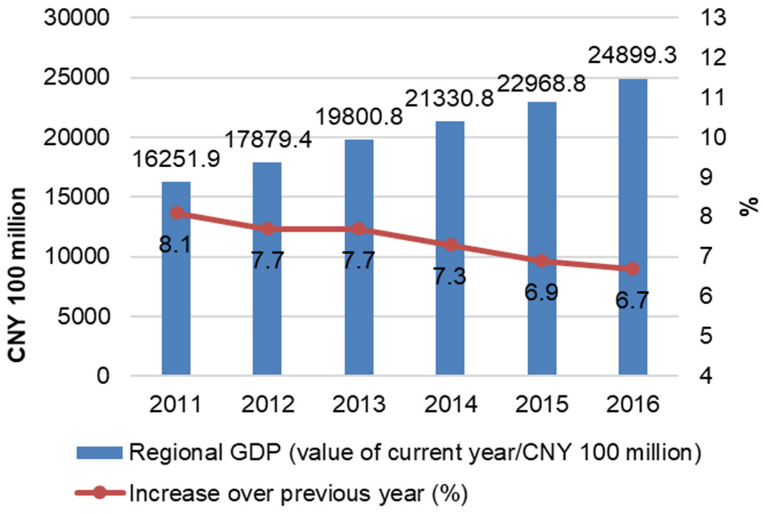


Table 22-1 GDP of Beijing in 2016

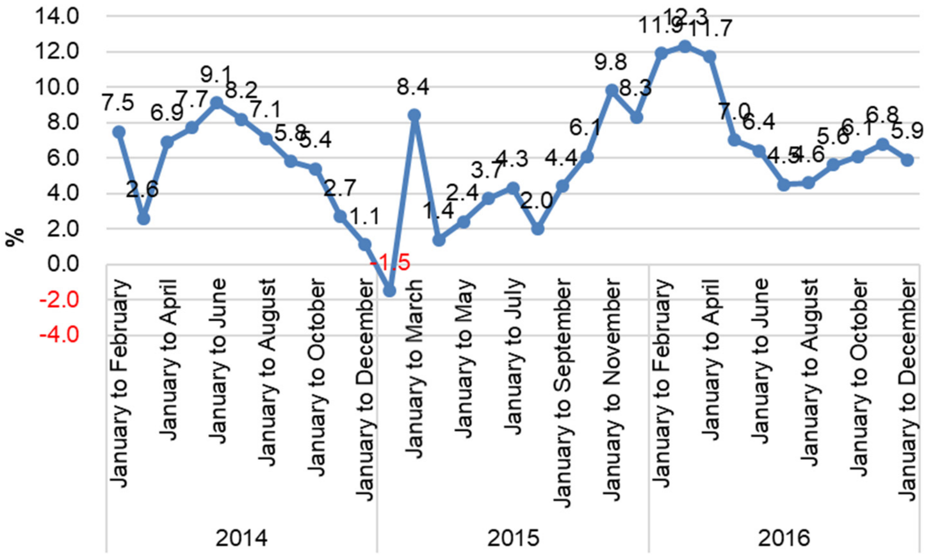
Unit: CNY 100 million, %

Index	Absolute number	Increase over previous year	Proportion
Regional GDP	24899.3	6.7	100
By industries:	-	-	-
Primary industry	129.6	-8.8	0.5
Secondary industry	4774.4	5.6	19.2
Tertiary industry	19995.3	7.1	80.3
By sectors:	-	-	-
Agriculture, forestry, animal husbandry and fishery	132	-8.7	0.5
Industry	3884.9	5	15.6
Construction	102.5	7.7	0.4
Wholesale and retail	2352.9	2	9.4
Transportation, warehousing and post	1060.7	6.6	4.3
Accommodation and catering	411.8	0.9	1.7
Information transmission, software and IT services	2697.9	11.3	10.8
Finance	4266.8	9.3	17.1
Real estate	1672.7	5.5	6.7
Lease and commercial services	1835.2	1.6	7.4
Scientific research and technical services	2077.9	10.2	8.3

Water conservancy, environment and public facility management	202.5	8.7	0.8
Resident services, repair and other services	159.7	9.1	0.6
Education	1089	9.1	4.4
Health and social work	635.6	7.2	2.6
Culture, sports and entertainment	583.5	7.8	2.3
Public management, social security and social organization	812.7	9.2	3.3

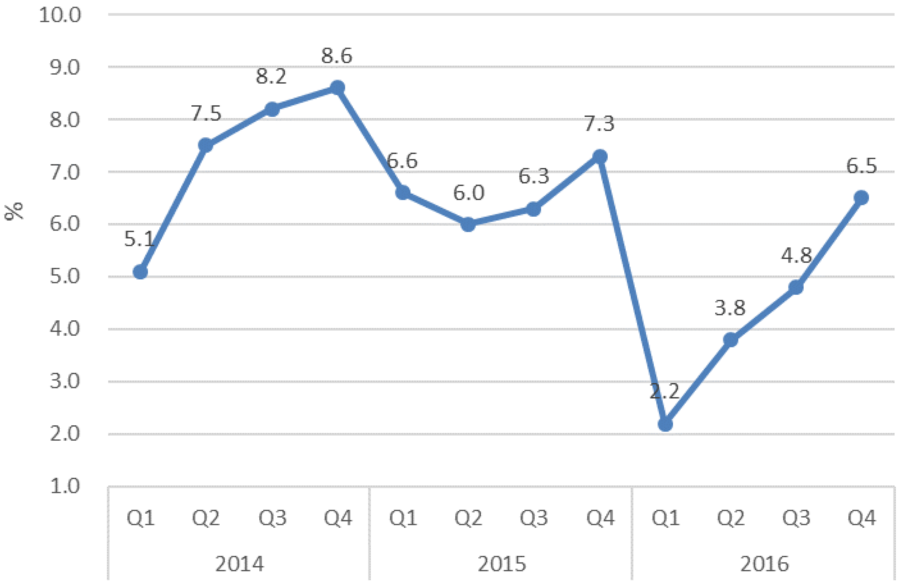
Steady investment growth and sound development of key fields. In 2016, Beijing invested CNY 846.17 billion in social fixed assets , increasing by 5.9% over previous year, among which, completed infrastructure investment was CNY 239.95 billion, increasing by 10.3%, with a contribution rate of 47.8% to investment increase. Investment of key industries increased positively, where the investment of lease and commercial services, hi-tech manufacturing, and culture, sports and entertainment respectively increased by 99.9%, 61.3% and 55.2%. By industries, the completed investment of primary industry, secondary industry and tertiary industry (including real estate development) was respectively CNY 9.98 billion (decreasing by 10.1%), CNY 72.29 billion (increasing by 6.8%) and CNY 763.9 billion (increasing by 6.1%).

Figure 22-2 Accumulative Growth Rate of Fixed Assets Investment in Beijing Since 2014



Steady rise in consumer market and continuous upgrading of consumption structure. In 2016, Beijing achieved total consumption of CNY 2 trillion, increasing by 8.1% over previous year, among which, service consumption was CNY 892.11 billion, increasing by 10.1%; total retail sales of social consumer goods was CNY 1.10051 trillion, increasing by 6.5%. Online sales was the main driving force of increase in retail sales, where wholesale and retail enterprises above designated size achieved online retail sales of CNY 204.9 billion, increasing by 20%, taking up 18.6% of the total retail sales of social consumer goods, and driving increase in retail sales of Beijing for 3.3%. Information consumption, culture, sports and entertainment consumption, and green consumption kept growing quickly. In the retail sales of wholesale and retail enterprises above designated size, the retail sales of communication equipment commodities, sports and entertainment products, and new energy vehicle commodities increased respectively by 8.8%, 21.1% and 2.7 times over previous year.

Figure 22-3 Accumulative Growth Rate of Total Retail Sales of Social Consumer Goods in Beijing Since 2014



Continuous decrease of total import and export value. In 2016, Beijing realized total import and export value of CNY 1.86252 trillion, decreasing by 6.1%, with decrease rate reduced by 16.2% over previous year, among which, the total import value was CNY 1.52071 trillion, decreasing by 7.5%, with decrease rate reduced by 16.7%; the total export value was CNY 341.81 billion, where the growth rate turned from negative to positive, with an increase of 0.7% and growth rate rise of 12%.

Tianjin

In 2016, economy in Tianjin experienced steady progress and sound development, with further improved development quality and benefits, new progress in industry transformation and upgrading, and continuously increased proportion of tertiary industry. In 2016, GDP of Tianjin was CNY 1.788539 trillion, with a year-on-year growth of 9.0% calculated at comparable prices, which is 2.3% higher than the national year-on-year growth, remaining at front position in China. From the perspective of three industries, the value-added of primary industry was CNY 22.022 billion, with an increase of 3.0% and a growth rate rise of 0.5% on year-on-year basis; the value-added of secondary industry was CNY 800.387 billion, with an increase of 8.0% and a growth rate drop of 1.2% on year-on-year basis, where the value-added of industry was CNY 723.880 billion, with an increase of 8.3%; the value-added of tertiary industry was CNY 966.130 billion, with an increase of 10.0% and a growth rate rise of 0.4% on year-on-year basis. The structural proportion of three industries was changed from 1.27:46.70:52.03 in 2015 to 1.23:44.75:54.02 in 2016, with proportion of tertiary industry increased by 1.99%.

Figure 22-4 GDP Growth in Tianjin

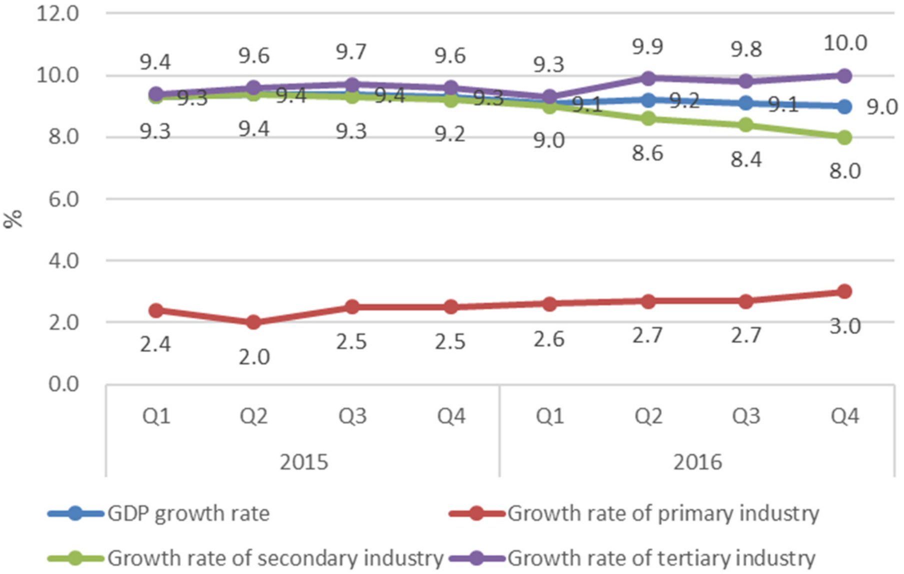
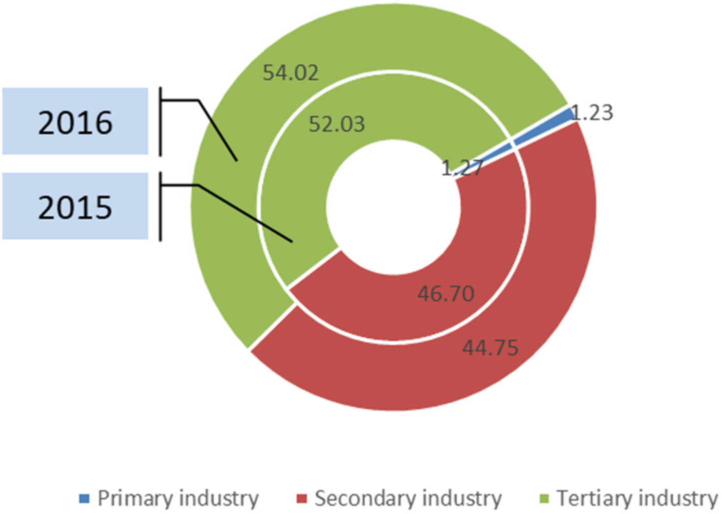


Figure 22-5 Structural Change of Industries in Tianjin



Rapid growth in investment and steady support by physical investment. In 2016, Tianjin achieved social fixed assets investment of CNY 1.462922 trillion, increasing by 12.0%. In fixed assets investment (excluding peasant households), the investment of primary, secondary and tertiary industries was respectively CNY 28.915 billion, CNY 394.048 billion and CNY 1.037656 trillion (with the proportion reaching 71.0%, rising by 1.3% over previous year), with a respective increase of 19.5%, 6.5% and 14.0%, where the investment of lease and commercial services, technology, and culture respectively increased by 58.5%, 1.1 times and 25.1%. The dominant position of physical investment was further promoted, and the completed investment of real economy was CNY 959.006 billion, increasing by 17.2% and taking up 65.7% of fixed assets investment. Infrastructure investment was CNY 271.612 billion, taking up 18.6% of fixed assets investment. As various favourable policies promoted steady and rapid development of real estate, real estate development investment was CNY 230.001 billion, with an increase of 22.9% and a year-on-year growth of 12.8%.

Year-on-year growth of consumption and obvious consumption upgrading trend. In 2016, Tianjin achieved total retail sales of social consumer goods of CNY 563.581 billion, increasing by 7.2%. From the perspective of consumption hot spots, sales of sports and entertainment commodities was prosperous, with sports and entertainment products above designated size increasing by 29.4%; sales of leisure commodities was good, with retail sales of cosmetics and electronic audio and video products respectively increasing by 6.4% and 8.6%; tourism and exhibition activities were flourishing and became new growth points stimulating consumption, with 142 cruise-times accepted in the whole year, and airport passenger throughput as 16.8719 million person-times, increasing by 17.9%; animated real estate market drove continuous prosperity of relevant consumption, with retail sales of building materials and home appliances respectively increasing by 39.9% and

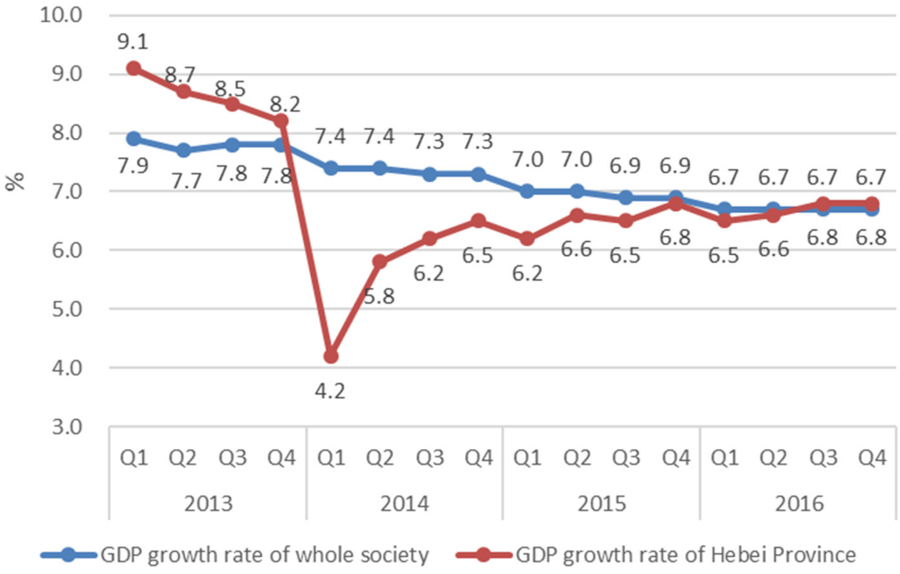
13.0%; automobile consumption steadily increased, with retail sales of CNY 95.176 billion, increasing by 17.3%; public catering consumption remained active, with turnover of accommodation and catering industry below designated size as CNY 67.917 billion, increasing by 13.1% and taking up 81.9% of the turnover of Tianjin. From the perspective of consumption pattern, Internet retail developed rapidly and drove online and offline integrative development of commerce, and online retail sales of organizations above designated size in the whole year was CNY 38.314 billion, increasing by 44.6%, taking up 12.1% of total retail sales of social consumer goods above designated size, with its proportion increasing by 3.2% over previous year, and making the number of enterprises with online retail scale over CNY 1 billion reach 10.

New progress in foreign trade structure adjustment and narrowing decrease in export. The total import and export value of Tianjin in the whole year was USD 102.651 billion, decreasing by 10.2%, among which, the export value was USD 44.286 billion, with an increase of 13.4% and the decrease rate reduced by 12.6% over the beginning of the year. From the perspective of export pattern, general trade export value was USD 21.042 billion, taking up 47.5% of Tianjin's export, with a year-on-year increase of 4.4%; processing trade export value was USD 20.228 billion, taking up 45.7% of Tianjin's export. New trade businesses represented by foreign trade integrated service enterprises and cross-border e-commerce presented the fastest development.

Hebei

In 2016, Hebei Province showed generally steady economic operation, reached a new level in economic aggregate, presented new changes in industrial structure, realized new breakthrough in kinetic energy conversion, made solid progress in JJJ's integrated development, fully neutralized excess capacity and accelerated the pace of transformation and upgrading. GDP of Hebei was CNY 3.18279 trillion, increasing by 6.8% over the same period of last year and being even with that of the same period calculated at comparable prices, and compared with surrounding provinces and municipalities (increasing by 7.6%, 8.1%, 4.5%, 6.7% and 9% respectively in Shandong, Henan, Shanxi, Beijing and Tianjin), the growth rate of Hebei was low, while the economic growth rate of Hebei was steady compared with the general falling tendency in the growth rate of the provinces. Among them, the value-added of primary, secondary and tertiary industries was respectively CNY 349.28 billion, CNY 1.50585 trillion and CNY 1.32766 trillion, with a respective increase of 3.5%, 4.9% and 9.9%. In 2016, the economic growth rate remained within a reasonable range, the industrial structure was continuously adjusted, and the proportion of three industries was respectively adjusted from 11.5:48.3:40.2 in 2015 to 11:47.3:41.7, with the proportion of secondary industry declining continuously and that of tertiary industry rising.

Figure 22-6 National and Hebei GDP Change in Recent Years



Recovery of growth rate of fixed assets investment and continuously optimized investment structure. Hebei achieved social fixed assets investment of CNY 3.175 trillion, increasing by 7.8% over previous year, among which, the fixed assets investment (excluding peasant households) was CNY 3.13401 trillion, increasing by 8.4%. The investment of primary, secondary and tertiary industries was respectively CNY 153.98 billion, CNY 1.57588 trillion and CNY 1.40415 trillion, respectively increasing by 9.3%, 7.6% and 9.3%. Industrial technical innovation investment was CNY 937.59 billion, increasing by 4.4% and taking up 59.4% of industrial investment. Infrastructure investment was CNY 714.31 billion, increasing by 15.7% and taking up 22.8% of fixed assets investment (excluding peasant households). Private fixed assets investment was CNY 2.40347 trillion, increasing by 5.6%. Hi-tech industry investment was CNY 413.68 billion, increasing by 10.7%, taking up 13.2% of fixed assets investment (excluding peasant households), and driving 1.4% of investment increase. Service industry investment increased continuously and was CNY 1.40415 trillion in the whole year, with a year-on-year growth of 9.3%, or 0.9% higher than the average investment of Hebei, taking up 44.8% of total investment, and driving 4.1% of fixed assets investment increase. Real estate development investment was CNY 469.56 billion, increasing by 9.6% over previous year, where residential investment increased by 9.9%, and the sales area of commercial residential buildings was 66.823 million square meters, increasing by 14.1%.

Steady growth in consumer market, becoming the first driving force of economic growth. Hebei achieved total retail sales of social consumer goods of CNY 1.43647 trillion, increasing by 10.6% over previous year, among which, the retail sales of urban consumer goods was CNY 1.11957 trillion, increasing by 10.3%; the retail sales of countryside consumer goods was CNY 316.9 billion, increasing by 11.4%. In retail sales of commodities of wholesale and retail enterprises (organizations) above designated size, grain and oils and food increased by 6.8%, beverages increased by 10.5%, liquor & tobacco increased by 13.7%, clothes, shoes and hats, knitwear and textile increased by 4.3%, daily necessities increased by 5.5%, traditional Chinese and western medicines increased by 15.3%, furniture increased by 20.8%, building and decoration materials increased by 12.3%, and automobile increased by 10.9%. Consumption demand had a greater driving force to economic growth than investment demand. In 2016, the contribution rate of final consumption to economic growth was 60.5%, increasing by 10.9% on year-on-year basis; in the annual economic growth of 6.8%, consumption demand took up 4.1%, which is 0.7% higher than that of investment.

Narrowing decrease in export. Hebei realized total import and export value of CNY 307.47 billion, decreasing by 3.7%, with decrease rate rising by 10.5% over previous year, among which, the total export value was CNY 201.45 billion, decreasing by 1.3%; the total import value was CNY 106.02 billion, decreasing by 8.0%. Export value of textile yarn, fabric and products was CNY 11.04 billion, increasing by 9.4%; that of clothes and clothing accessories was CNY 24.28 billion, increasing by 2.3%; that of steel was CNY 53.47 billion, decreasing by 12.5%; that of agricultural products was CNY 9.97 billion, decreasing by 3.0%; that of electromechanical products was CNY 54.53 billion, increasing by 0.02%; that of hi-tech products was CNY 12.51 billion, decreasing by 14.6%.

Energy Development Evaluation

Beijing

(1)Energy development

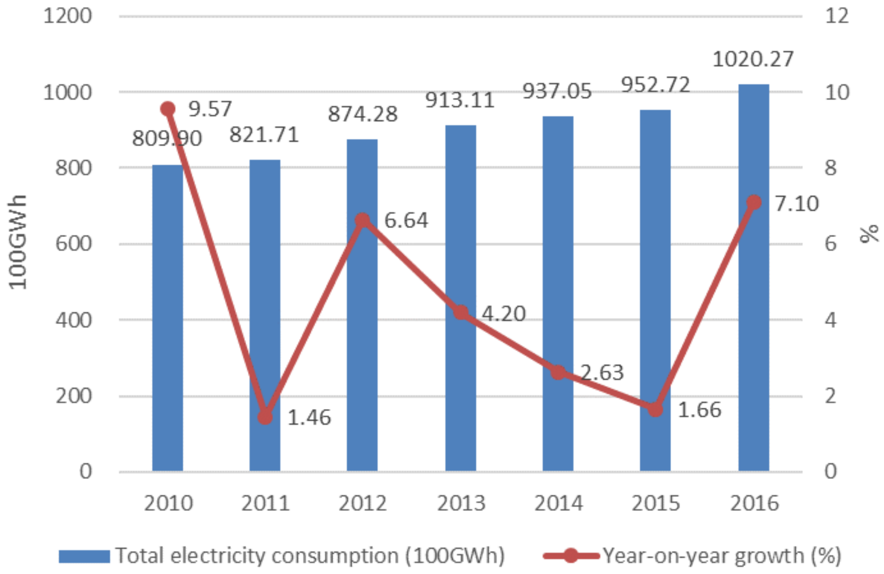
In 2016, benefiting from continuous reduction of traditional energy capacity, clean energy resource channel development and acceleration of infrastructure enhancement, the energy supply of Beijing was generally sufficient, and the price level continuously dropped. All electricity-coals are supplied from outside and are transported completely by railway. After the heating season of 2016 to 2017, four coal-fired thermal power plants in Beijing were shut down, and Beijing entered an era of coal free power generation. As Beijing reinforces structural adjustment and optimization of energy consumption, Chaoyang District, Haidian District, Fengtai District and Shijingshan District are expected to realize "coal free" heating by 2017; this "coal free" process will be expanded to countryside in plain area of Beijing by 2020 and Olympic Winter Games related areas by 2022.

Beijing's natural gas market is featured by complete reliance on transfer, great market demand and large seasonal difference in gas consumption. 98% of natural gas demanded in Beijing is currently transported via Jingbian-Beijing Pipeline. The gas transmission and distribution facility system in Beijing will be further improved in the future, with actively accurate control in seasonal peak and a safe natural gas supply system built. The construction of Beijing Section of Jingbian-Beijing Pipeline 4 and West Sixth Ring Natural Gas Pipeline Project is in progress smoothly, where Jingbian-Beijing Pipeline 4 is planned to be completed in 2017, whose daily gas transportation capacity will be increased by 70 million cubic meters.

(2)Electricity consumption

The total electricity consumption and year-on-year growth of Beijing during 2010-2016 are shown in Figure 22-7. In 2016, the accumulative total electricity consumption of Beijing was 102.027TWh. Due to severe winter and sweltering summer in 2016, the electricity consumption of Beijing presented an obvious increase, with a year-on-year growth of 7.09%. Among them, the accumulative electricity consumption of primary, secondary and tertiary industries as well as urban and rural households was respectively 1.962TWh, 33.432TWh, 47.09TWh and 19.543TWh, with a respective year-on-year growth of 6.06%, 3.24%, 8.09% and 11.83%. The structure of electricity consumption of three industries and urban and rural resident living was 1.92:32.77:46.15:19.15, where the proportion of secondary industry decreased by 1.22%, that of tertiary industry increased by 0.43% and that of resident living increased by 0.81% compared with last year.

Figure 22-7 Annually Accumulative Total Electricity Consumption and Year-on-year Growth of Beijing during 2010-2016



The electricity consumption of key industries in Beijing in 2016 is shown in Table 22-2. In Beijing in 2016, the electricity consumption of petroleum processing, coking and nuclear fuel processing industry was 2.28TWh, with accumulative decrease of 115GWh and a year-on-year decrease of 4.80%; the electricity consumption of general and special equipment manufacturing was approximately 1.844TWh, with accumulative increase of 23GWh and a year-on-year growth of 1.29%; the electricity consumption of transportation, electrical and electronic equipment manufacturing was 5.54TWh, with accumulative increase of 236GWh and a year-on-year growth of 4.45%; the electricity consumption of transportation was 4.29TWh, with accumulative increase of 221GWh and a year-on-year growth of 5.44%; the electricity consumption of information transmission, computer service and software industry was 3.37TWh, with accumulative increase of 504GWh and a year-on-year growth of 17.59%; the electricity consumption of real estate was 11.04TWh, with accumulative increase of 737GWh and a year-on-year growth of 7.15%.

Table 22-2 Electricity Consumption of Key Industries in Beijing from January to December 2016

Unit: 100GWh, %

Key industry	Accumulative value	Accumulative value of previous year	Growth rate
Petroleum processing, coking and nuclear fuel processing industry	22.8	24.0	-4.80%
General and special equipment manufacturing	18.4	18.2	1.29%
Transportation, electrical and electronic equipment manufacturing	55.4	53.0	4.45%
Transportation	42.9	40.6	5.44%
Information transmission, computer service and software industry	33.7	28.7	17.59%
Real estate	110.4	103.0	7.15%

(3)Power supply

As of the end of 2016, the total installed capacity of generation units in Beijing was 11.0314GW, where the hydropower installed capacity was 983MW, taking up 8.9% of the total installed generating capacity; as after the heating season of 2016 - 2017, four coal-fired thermal power plants in Beijing were shut down and Beijing entered an era of coal free power generation, the gas power generation installed capacity was 9.709GW, taking up 88.1% of the total installed generating capacity; as there is less wind energy resource in Beijing and only northwestern mountain area is suitable for constructing wind power plant, the wind power installed capacity was 186MW, taking up 1.7% of the total installed generating capacity; solar power installed capacity was 154MW, taking up 1.4% of the total installed generating capacity.

In 2016, the total generating capacity of generation units in Beijing was 43.562TWh, with a year-on-year growth of 3.5%, where the generating capacity of hydropower, thermal power, wind power and solar power generation units was respectively 1.213TWh, 41.916TWh, 330GWh and 109GWh, with a respective year-on-year growth of 85.8%, 1.9%, 27.4% and 169.9%. In 2016, the utilization hours of generating units in Beijing was 3,959h, with a year-on-year growth of 4.3%, where the utilization hours of hydropower, thermal power and wind power generating units was respectively 1,234h, 4,320h and 1,750h, with a respective year-on-year growth of 85.8%, 3.9% and 2.8%.

As of the end of 2016, there were 412 substations rated 110kV and above in operation in Beijing, with substation capacity of 87,580,000kVA; there were 785 overhead lines, with total length of 7,042km; there were 958 cable lines, with total length of 1,892km. In 2016, the power receiving capacity of tie line was 60.456TWh, with a year-on-year growth of 15.21% compared with 52.473TWh, and the percentage of external power receiving was 59.08%.

With limited generating capacity of power plants, Beijing grid relies on North China grid for integrated coordination of supply and demand as a typical receiving-end grid, which is connected with North China grid through 10 transmission channels (20 lines), with nearly 70% of power coming from outside of Beijing.

Tianjin

(1)Energy development

In 2016, energy supply of Tianjin was generally sufficient, where power plants received coal of 11.47 million tons, consumed coal of 11.22 million tons and stocked coal of 760,000 tons, the electric coal supply of directly dispatched power plants was sufficient and steady, and the coal stock of coal-fired power plants could basically maintain for above 10 days; the natural crude oil production was 32.733 million tons, with a year-on-year decrease of 6.39%, and the natural crude oil and product oil consumed by industries above designated scale were respectively 14.0727 million tons and 451,800 tons, with a respective year-on-year decrease of 12.8% and 54.0%, see Table for accumulative production and increase of natural crude oil; the natural gas production was approximately 1.97 billion cubic meters, with a year-on-year decrease of 4.09%, and the natural gas consumed by industries above designated scale was 4.967 billion cubic meters, with year-on-year growth of 19.1%, see Table 22-4 for accumulative production and a year-on-year growth of natural gas.

Table 22-3 Accumulative Production and Growth of Natural Crude Oil in Tianjin in 2016

Unit: 10,000 tons, %	January to February	March	April	May	June	July
Accumulative production	568.0	854.4	1129.8	1413.7	1688.1	1968.5
Production in current month on year-on-year basis	3.8	1.0	-1.6	-2.3	-2.8	-7.8
Month	**August**	**September**	**October**	**November**	**December**	
Accumulative production	2235.6	2493.4	2760.7	3014.5	3273.3	
Production in current month on year-on-year basis	-12.4	-12.3	-12.2	-14.1	-16.5	

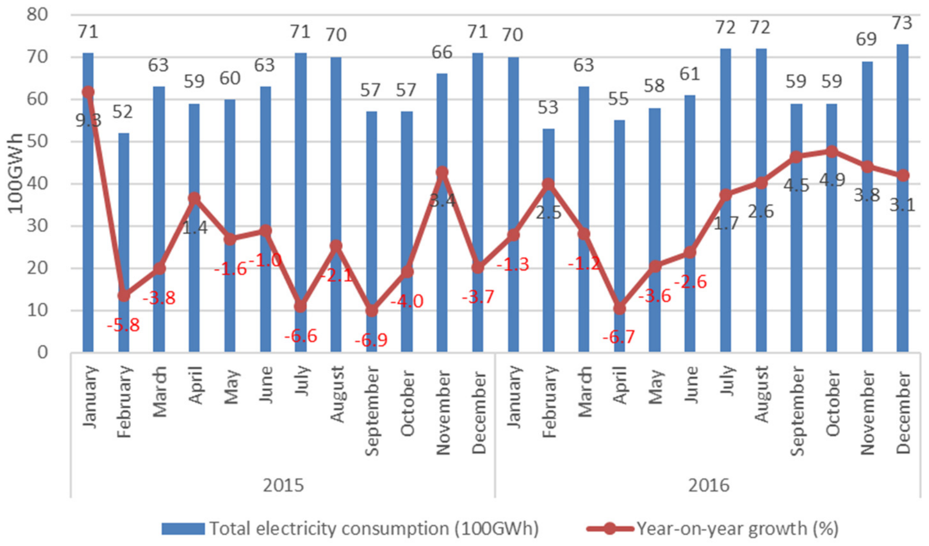
Table 22-4 Accumulative Production and Growth of Natural Gas in Tianjin in 2016

Unit: 100 million cubic meters, %	January to February	March	April	May	June	July
Accumulative production	3.6	5.4	7.0	8.4	9.9	11.5
Production in current month on year-on-year basis	4.3	0.8	-5.2	-19.2	-14.4	-8.9
Month	**August**	**September**	**October**	**November**	**December**	
Accumulative production	12.9	14.5	16.1	17.8	19.3	
Production in current month on year-on-year basis	-13.2	-2.5	0	1.6	-4.2	

(2)Electricity consumption

In 2016, under combined influence of steady growth of macro economy, solid progress in structural adjustment, rebounding growth of industrial power consumption in the next half year and low electricity consumption the previous year, the growth rate of power consumption in Tianjin rose again to complete accumulative total electricity consumption of 76.332TWh, with a year-on-year growth of 0.64%, and the year-on-year growth rate at the corresponding period shifted from negative to positive and rose by 2.47%.

Figure 22-8 Total Electricity Consumption and Year-on-year Growth of Tianjin in Each Month of 2015-2016



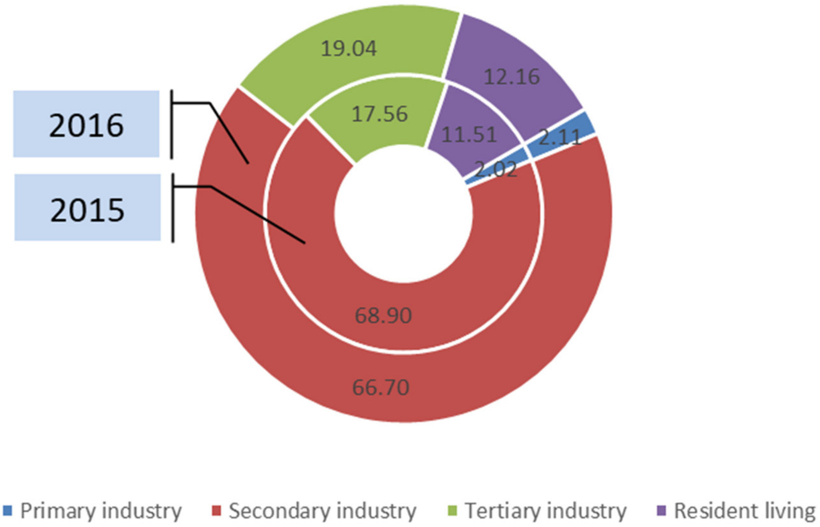
Steady growth in electricity consumption of the primary industry. Driven by accelerated agriculture transformation and upgrading, continuous structural adjustment and optimization, rapid development of modern urban agriculture, green leisure agriculture and special breeding industry, the accumulative electricity consumption of primary industry in Tianjin was 1.608TWh, with a year-on-year growth of 4.87%, taking up 2.11% of the total electricity consumption, and driving 0.1% growth in total electricity consumption. **Continuous decrease in domestic electricity consumption, with narrowing decrease.** Due to policy influences of economic structure transformation and cutting overcapacity, the accumulative electricity consumption of secondary industry in Tianjin was 50.911TWh, with a year-on-year decrease of 2.59%, with decrease rate reduced by 2.53% over previous year, taking up 66.70% of the total electricity consumption, and driving down 1.78% of growth in total electricity consumption. Among them, the electricity consumption of iron and steel industry with large proportion in Tianjin continued decreasing, with a year-on-year decrease of 9.98%; due to influence of "relocation of Tianjin Dagu Chemical Co., Ltd. and Tianjin Botian Chemical Trade Co., Ltd.", the electricity consumption of chemical industry also tended to decrease, with a year-on-year decrease of 17.28%. **Steady rise in electricity consumption of the tertiary industry.** As Tianjin continued reinforcing economic structure adjustment, the accumulative electricity consumption of tertiary industry in Tianjin was 14.53TWh, with a year-on-year growth of 9.06%, taking up 19.04% of the total electricity consumption, and driving 1.59% of growth in total electricity consumption. Exception for construction industry in tertiary industry, the electricity consumption of other sectors presented positive growth. **Continuous growth in domestic electricity consumption.** Due to influences of extreme weather, continuous population increase and leap year, the accumulative domestic electricity consumption in Tianjin was 9.282TWh, with a year-on-year growth of 6.33%, taking up 12.16% of the total electricity consumption, and driving 0.73% of growth in total electricity consumption.

Table 22-5 Electricity Consumption of Whole Society and by Industries in Tianjin during 2015-2016

Unit: 100GWh, %		2016				2015			
		Electricity consumption	Year-on-year growth	Driving rate	Electricity consuming structure	Electricity consumption	Year-on-year growth	Driving rate	Electricity consuming structure
Whole society		**763.32**	**0.64**	**0.64**	**100.00**	**758.49**	**-1.83**	**-1.83**	**100.00**
Primary industry		16.08	4.87	0.10	2.11	15.34	3.00	0.06	2.02
Secondary industry		509.11	-2.59	-1.78	66.70	522.63	-5.12	-3.65	68.90
Tertiary industry		145.30	9.06	1.59	19.04	133.23	3.45	0.58	17.56
Households		92.82	6.33	0.73	12.16	87.29	11.79	1.19	11.51
Industry		497.73	-2.44	-1.64	65.21	510.18	-5.05	-3.51	67.26
Including	Light industry	74.61	5.56	0.52	9.77	70.69	-0.57	-0.05	9.32
	Heavy industry	423.12	-3.73	-2.16	55.43	439.50	-5.74	-3.46	57.94

From the perspective of structure, the total electricity consumption of Tianjin was still dominant by secondary industry, while the proportion of electricity consumption of primary industry, tertiary industry and households continued rising. The proportion of electricity consumption of three industries and households in the total electricity consumption in Tianjin in 2016 was respectively 2.11:66.70:19.04:12.16. Due to influences of industrial structure adjustment and industrial transformation and upgrading, the proportion of electricity consumption of secondary industry continued decreasing and reached the lowest since the "12th Five-Year Plan" period, with a year-on-year decrease of 2.21%; the electricity consumption of primary industry, tertiary industry and households continued increasing, whose proportion of electricity consumption respectively increased by 0.08%, 1.47% and 0.65% compared with the same period of last year.

Figure 22-9 Electricity Consuming Structure of Tianjin in 2016 and 2015



From the perspective of electricity consumption ranking of industries, the top six industries in industrial electricity consumption in Tianjin were respectively: ①transportation, electrical and electronic equipment manufacturing, ②ferrous metal smelting and calendaring processing industry, ③chemical raw materials and chemicals manufacturing, ④metal product industry, ⑤general and special equipment manufacturing, and ⑥non-ferrous metal smelting and calendaring processing industry. The electricity consumption of transportation, electrical and electronic equipment manufacturing ranked the first from the second by surpassing that of ferrous metal smelting and calendaring processing industry.

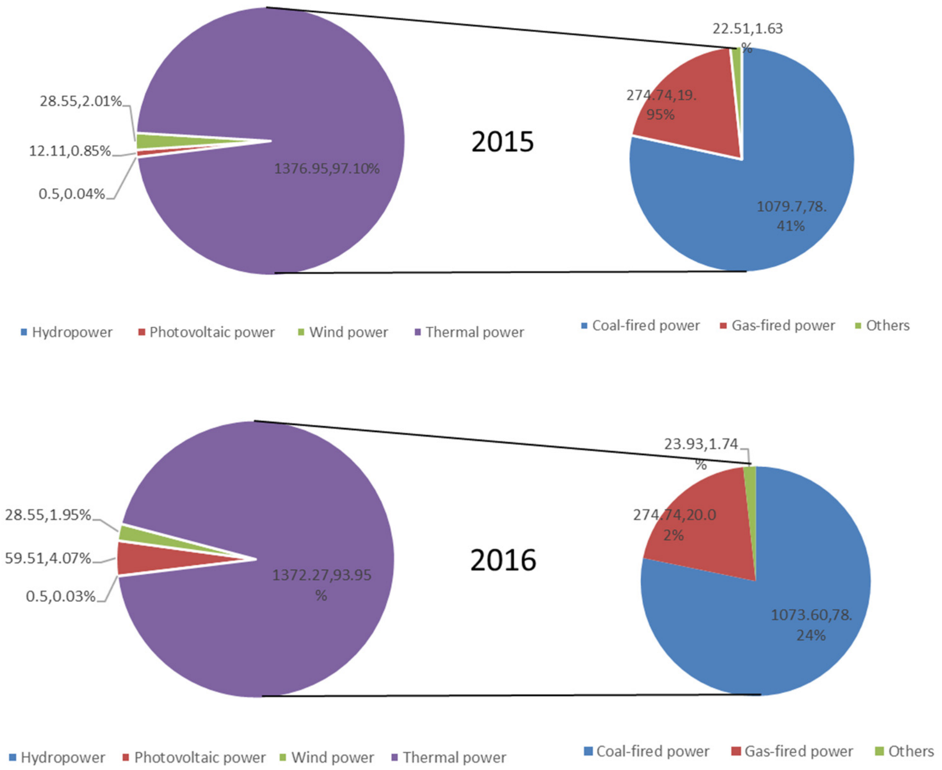
Table22-6 Electricity Consumption of Key Industries in Tianjin in 2016

Unit: 100GWh, %	Electricity consumption in 2016	Year-on-year growth rate	Driving rate to industry	Proportion to industry
Industrial electricity consumption	**497.7308**	**-2.44**	**-2.44**	**100.00**
Transportation, electrical and electronic equipment manufacturing	70.96	5.69	0.75	14.26
Ferrous metal smelting and calendaring processing industry	60.72	-9.98	-1.32	12.20
Chemical raw materials and chemicals manufacturing	53.94	-17.28	-2.21	10.84
Metal product industry	50.78	5.30	0.50	10.20
General and special equipment manufacturing	23.1012	3.75	0.16	4.64
Non-ferrous metal smelting and calendaring processing industry	16.27	-19.91	-0.79	3.27
Non-metal mineral product industry	15.23	5.17	0.15	3.06
Total of four energy-intensive industries	**146.16**	**-12.71**	**-4.17**	**29.37**

(3)Power supply

As of the end of 2016, the total installed capacity of generation units in Tianjin was 14.67GW, where the hydropower installed capacity was 5MW; and the installed capacity of thermal power, wind power and solar power was respectively 13.78GW, 290MW and 600MW, respectively taking up 94.0%, 1.9% and 4.1% of the total installed capacity. From the perspective of power supply structure, the proportion of installed capacity of thermal power, wind power, solar energy and hydropower was changed from 97.10:2.01:0.85:0.04 at the end of 2015 to 93.95:1.95:4.07:0.03, where the solar energy installed capacity increased remarkably, with the proportion increasing by 3.22%, while the proportion of thermal power installed capacity decreased by 3.15%.

Figure 22-10 Installed Capacity of Grids in Tianjin in 2015 and 2016



In 2016, the accumulative total generating capacity in Tianjin was 60TWh, with a year-on-year decrease of 0.14%, and the average utilization hours of generating units were 4,122, with a year-on-year decrease of 310h, where the thermal power generating capacity was 59.101TWh, with a year-on-year decrease of 0.47%, and the average utilization hours of equipment were 4,310, with a year-on-year decrease of 202h, and in thermal power generation units, the generating capacity of gas-fired power plants was 10.422TWh, with a year-on-year growth of 30.99%; the hydropower generating capacity was 3.36GWh, with a year-on-year decrease of 77.03%, and the average utilization hours of equipment were 672, with a year-on-year decrease of 2,254h; the wind power generating capacity was 587GWh, with a year-on-year decrease of 6.84%, and the average utilization hours of equipment were 2,055, with a year-on-year decrease of 150h; due to influence of large quantity of newly invested photovoltaic power installed capacity, the solar energy generating capacity was 309GWh, with a year-on-year growth of 386.32%, and the average utilization hours of equipment were 539, with a year-on-year decrease of 64h.

As of the end of 2016, there were 229 substations rated 110kV and above in operation in Tianjin, with substation capacity of 65,789,000kVA and there were 619 lines, with total length of 9,332.4km.

Hebei

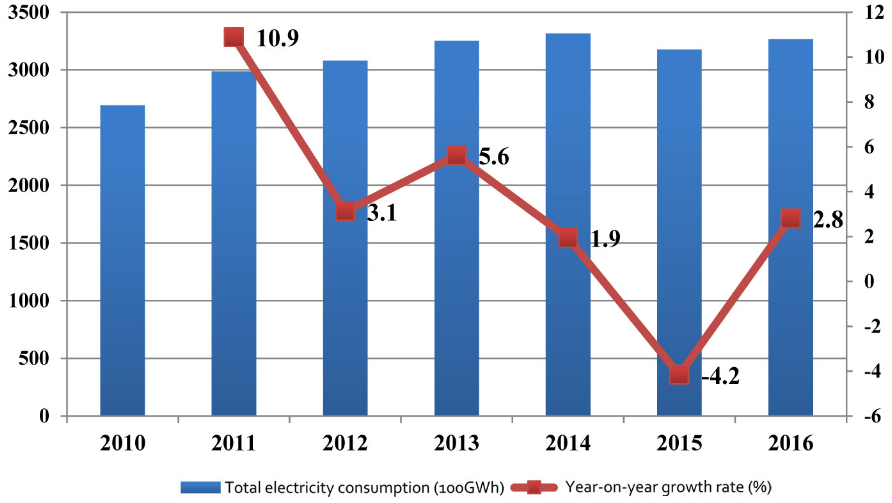
(1)Energy development

In 2016, the energy supply of Hebei was relatively sufficient in general, where the coal production was 66.237 million tons, with a year-on-year decrease of 19.4%; the coal sales was 80.172 million tons, decreasing by 5.5%; the crude oil production was 5.4596 million tons, with a year-on-year decrease of 5.9%; the completed crude oil processing volume was 17.3253 million tons, with a year-on-year growth of 5.8%; the gasoline production was 4.7588 million tons, increasing by 10.0%; the kerosene production was 579,000 tons, increasing by 31.1%; the diesel production was 5.0192 million tons, increasing by 0.8%; natural gas operation was safe and stable, and the natural gas production was 778 million cubic meters, with a year-on-year decrease of 25.4%; the total gas supply was 4.716 billion cubic meters, increasing by 2.8%; the total gas consumption was 4.774 billion cubic meters, increasing by 3.2%; the accumulative supply-demand difference in the whole year was 65.474 million cubic meters, with daily average supply deficiency of 196,000 cubic meters and supplied deficiency of 116 million cubic meters by purchasing gas outside Hebei.

(2) Electricity consumption

In terms of electricity consumption in 2016, the total electricity consumption of Hebei reached 326.2TWh, ranking the fifth in China, among which, the accumulative electricity consumption of primary industry was 9.74TWh, with a year-on-year decrease of 1.1%; that of secondary industry was 235.49TWh, with a year-on-year growth of 1.0%; that of tertiary industry was 41.72TWh, with a year-on-year growth of 11.9%; that of urban and rural households was 39.51TWh, with a year-on-year growth of 6.3%. The structure of electricity consumption of three industries and urban and rural households was 2.98:72.13:12.78:12.10.

Figure 22-11 Annually Accumulative Total Electricity Consumption and Year-on-year Growth of Hebei during 2010-2016



In Hebei in 2016, the electricity consumption of transportation, electrical and electronic equipment manufacturing was 9.54TWh, with a year-on-year growth of 8.9%; that of information transmission, computer service and software industry was 2.54TWh, with a year-on-year growth of 24.6%; that of commerce, accommodation and catering industry was 13.62TWh, with a year-on-year growth of 10.5%; that of finance, real estate, business and resident services was 574MWh, with a year-on-year growth of 14.3%; that of public utilities and management organizations was 1.028GWh, with a year-on-year growth of 12.3%.

(3) Power supply

As of the end of 2016, the total installed capacity of generation units in Hebei was 62.75GW, where the installed capacity of hydropower, thermal power, wind power and solar power was respectively 1.824GW, 45.101GW, 11.379GW and 4.427GW, respectively taking up 2.9%, 71.9%, 18.1% and 7.1% of the total installed generating capacity.

In 2016, the total generating capacity of generation units in Hebei was 247.6TWh, where the generating capacity of hydropower, thermal power, wind power and solar power generation units was respectively 2.37TWh, 219.58TWh, 21.64TWh and 4.01TWh, respectively taking up approximately 1.0%, 88.7%, 8.7% and 1.6% of the total generating capacity.

As of the end of December 2016, Southern Hebei Grid had 40 substations rated 500kV, 91 main transformers and 78,450,000kVA substation capacity; there were 132 power transmission lines rated 500kV in total (excluding tie lines between provinces), with total length of 9,170km. There were 303 substations rated 220kV, 687 main transformers and

111,730,000kVA substation capacity; there were 892 lines rated 220kV, with total length of 21,420km. There were 1,008 utility substations rated 110kV, 2,001 main transformers and 89.87GW capacity. There were 2,364 lines rated 110kV in total, with length of 28,334km.

Key issues in Development

Problems in economic development

The economic operation of JJJ is relatively steady in general, but its industrial development faces some prominent problems. In the context of complicated and changeable international situation as well as continuous promotion of various policies at home, JJJ is at a crucial stage of "supply-side structural reform". In the meantime, the development of traditional high energy-consumption sectors, such as steel and building material sectors, are restricted by constantly strengthening fog and haze governance, while new industries, such as equipment manufacturing and high and new technology industries develop fast, and the economic growth is at the stage of transiting from old driving forces to the new ones power. It can be learnt from the published economic data that the investment and consumption of JJJ are relatively stable, and the support for economic growth is further strengthened. On the other hand, export shows a rapid growth trend in general, but industrial growth rate is still low and far below the national average level, which indicates that problems still exist in industrial development.

The problems are mainly reflected in the great gaps in the economic development levels among Beijing, Tianjin and Hebei. Both Beijing and Tianjin are municipality directly under the Central Government and important central cities of Bohai Rim. As the capital of China, Beijing has exceptionaltechnological intelligence support and outstanding economic strength compared with other cities. Being close to Beijing is both an advantage and a disadvantage for Tianjin and Hebei. Many cities in Hebei are in mountainous area with backward traffic, communication and other infrastructures. Objectively, integrative economic development of JJJ requires various cities and regions developing in a similar pace, but showing their own features. Great economic gap among Beijing, Tianjin and Hebei regions seriously affects integrative economic development of JJJ. Meanwhile, Hebei is an important energy, steel, heavy and chemical base of China. Integration of JJJ does not only require transfer and governance of some heavy and chemical industries, but also demands upgrading and retrofit of such industries. Therefore, Hebei is under great pressure on air pollution control. Both Beijing and Tianjin are core cities of JJJ with similar economic strength, thus repeated construction is very likely to occur.

Problems in energy development

The energy demand of JJJ grows steadily, but energy security requirements are running high. From the perspective of economic development stages, Beijing has entered post-industrialization stage, Tianjin's industrialization has been completed basically, but Hebei is in the middle of industrialization. In the future, JJJ will enter the post-industrialization development stage when industrial energy consumption will reduce, and the energy consumption will be concentrated in fields such as building, traffic and consumerorientedservicesaccordingly. International experience shows that energy demand grows rapidly at the early and intermediate stages of industrialization and maintains steady growth at the later stage of industrialization with an elasticity coefficient less than 1. At post-industrialization stage, the growth rate of energy demand decreases, and energy demand tends to be stable gradually. JJJ becomes the new growth pole that drives the economic development of China under the new normal together with existing ones, such as Yangtze River Delta and Pearl River Delta regions. Energy is the "blood" of economic and social development. The industrial layout of continuous optimization and transformation of JJJ puts forward higher requirements for energy security.

Beijing, Tianjin and Hebei regions are subject to unbalanced development, and coordinated energy development needs to be driven by innovation badly. Due to imbalance in terms of economic development, system and mechanism, scientific and technological innovation, etc., among Beijing, Tianjin and Hebei regions, the energy efficiency levels among them are in serious polarization. In the coordinated development of Beijing, Tianjin and Hebei regions, coordinated energy development puts forward higher requirements and challenges for improving energy efficiency level, which needs to be driven by scientific and technological innovation as well as system and mechanism innovations. As a national innovation base of scientific research and development, further breakthroughs in new energy and new technologies adapting to future energy development, such as smart power grid, large-capacity energy storage, electric vehicle, energy internet and clean and efficient utilization of coal in JJJ, are necessary, so as to provide technical support for efficient and sustainable energy development. In the meantime, there is a large space in improving optimum allocation of resources through accelerating the improvement of energy policy system as well as reforms of relevant systems and mechanisms of JJJ under the general background of comprehensively deepening reform.

Problems in power development

The power grid peak regulation of JJJ becomes increasingly difficult, and the consumption problem of new energy keeps deteriorating. The power grid peak regulation of JJJ in heating season becomes increasingly difficult due to sluggish growth in power grid load, rapid increase of district heating area and constantly increasing gap between peak and valley loads. As a result, the contradiction among secure power supply, reliable heat supply and new energy consumption emerges gradually. In 2016, the wind curtailment of JJJ was 1.92TWh, with a year-on-year growth of 17.5% and a wind curtailment rate about 10.9%. Generally speaking, the renewable energy consumption of JJJ is still a tough problem. New installed capacity in Zhangjiakou and some other regions still remains high even with serious wind curtailment problem, leading to obvious aggravation of renewable integration problems. About 800MW of new wind power installed capacity and 3GW of new solar power installed capacity are expected for the power grid of JJJ in 2017, and thus the resource allocation ability needs to be improved further and development of transmission lines needs to be strengthened. In addition, it is in urgent need of establishing a new energy market trading mechanism, so as to promote consumption of new energy to a larger extent with market means.

Renewable energy development is unbalanced and power grid development is non-synchronous in JJJ. Wind power is the main force driving the renewable energy development of JJJ, which is of relatively high development and utilization degree. However, the penetration of photovoltaic and pumped storage power is relatively low. Among them, photovoltaic power is less than 4% of available resources, most of which is concentrated, and pumped storage capacity is less than 8%. Coordinated development of multiple energy resources needs to be improved further. On the other hand, the construction speed of power transmission lines cannot catch up with the speed of wind power development in regions like Zhangjiakou, which makes the transmission of large amount wind power impossible. . Nonsynchronous constructing periods of wind farms and their corresponding interconnection projects leads to power grid-connection lag, resource waste and loss of project investment benefit.

Influence Factors to Future Development

Macro-economic situation

China's economy shows stable-good trend, but downward pressure still exists, and challenges and uncertainties from external are growing. The root of prominent contradictions and problems faced by the economic operation of China is significant structural disequilibrium. 2017 is the deepening year of supply-side structural reform. Central Government will stick to the general work keynote of seeking improvement in stability and continue to implement positive fiscal policies and prudent monetary policies.

(1)Financial deficit will increase further with the increase of financial strength. It is pointed out in the government work report of 2017 that the deficit rate of 2017 is 3%, and the total financial deficit is CNY 2.38 trillion, which is CNY 200 billion higher than that (CNY 2.18 trillion) of 2016. It is clarified at the Central Economic Working Conference that positive fiscal policies will be further implemented in 2017, the fiscal policies should be more positive and effective, and budget layout should adapt to the demands of promoting supply-side structural reform, lowering tax burden of enterprises and guaranteeing people's livelihood. Under the general background of slowdown private investment, manufacturing investment and real estate investment, the Government needs to bear greater obligation. Both infrastructure expansion and improvement of people’s livelihood require continuous and high-speed expansion of government expenditures. The general public budget expenditure of Central Government in 2017 is CNY 9.5745 trillion, which is 6.1% higher that of the last year. Meanwhile, reducing enterprises’ tax burden is also an important embodiment of positive fiscal policies. Tax reduction effect of “replacing business tax with value-added tax” will be implemented better and further in 2017. In addition, there’s decreasing space on the tax fees of innovation and entrepreneurship as well as administrative and business charges, besides, social security premium rate also can be adjusted moderately. At the same time, considering poor prospects of several large taxes and slowdown of fiscal revenue due to reduction and slowdown of domestic demand, the general public budget revenue of Central Government in 2017 is CNY 7.8612 trillion, which is 3.8% higher than that of the last year.

(2)Monetary policies are robust and neutral, and more attention will be paid to risk prevention. It is pointed out at the Central Economic Working Conference that monetary policies will be kept robust and neutral, deleverage, bubble removal and risk prevention will become important factors of policy consideration. Central Bank will continue to pay high attention to market risk factors and control money supply valve. The objectives of M2 and social financing scale growth rate policy of 2017 are lowered to 12%, and a robust and neutral monetary policy direction is determined in government work report. Both the new trade policy and future monetary policy trend of the Federal Reserve will pose new challenges to Central Bank. It is widely believed that the Federal Reserve will raise interest rates in 2017. In order to cope with outflow risk of China's capital, Central Bank is likely to raise interest rates. However, the impetus of domestic economic demand side is decreasing obviously, and macro economy is still under downward pressure, which leads to more tense relation between foreign exchange management and money supply. When the devaluation pressure on RMB is relieved in 2017, it is necessary to cut deposit reserve ratio. Meanwhile, in case of increase of capital outflow scale, insufficient money supply will also force Central Bank to inject liquidity by reducing deposit reserve ratio.

(3)Supply-side structural reform will be further promoted. It is determined at the Central Economic Working Conference that "addressing overcapacity, reducing inventory, deleveraging, lowering costs, and bolstering areas of weakness" will be promoted in 2017 to make substantial progress. Problem solving direction is put forward for five tasks with specific deployment and clear focus. As for "addressing overcapacity", it is required to keep cutting excess capacity of steel and coal sectors, handle "zombie enterprises", prevent resurgence of the excess capacity cut, and cut overcapacity of other sectors with serious overcapacity. Compared with 2016, the difficulty of cutting overcapacity in 2017 increases significantly. It is expected that the overcapacity cutting scales of coal and steel sectors in 2017 are 200 million tons and 45 million tons respectively. As for "reducing inventory", it is needed to stick to classification regulation and implementing policies based on cities and regions, so as to combine reducing excess inventory with promoting urbanization of population. By the end of March 2017, the area of commercial housing for sale dropped 6.4% on year-on-year basis, and the decrease amplitude was increased by 3.2% compared with the end of the last year. In 2017, the Government will vigorously promote monetized resettlement of rebuilding run-down urban areas, and the monetized resettlement ratio will be increased to over 50% from 30% in 2015. As for "deleveraging", lowering enterprise leverage ratio is taken as the priority among priorities. The stable situation of macro economy since the second half of 2016 creates favourable condition for deleveraging. Profit recovery of enterprises increases enterprises' principal repayment capacity, and the lever of enterprise sector tends to be stable. By the end of February, the debt-to-asset ratio of industrial enterprises above designated scale was 56.2%, indicating a year-on-year decrease of 0.6%. There's large deleveraging space for state-owned enterprises in 2017. As for "lowering costs", it is required to increase efforts on reducing tax, fee and factor cost.

In January and February of 2017, the cost per CNY 100 of income from main business operations of industrial enterprises above designated scale was CNY 84.91, indicating a year-on-year decrease of CNY 0.28 and remarkable cost lowering effect. The tax cutting scale of replacing business tax by value-added tax exceeded CNY 500 billion in 2016, and the tax cutting effect had been fully released. There's limited tax cutting space in 2017, but it is still worth looking forward to lowering the 17% industrial and commercial value-added tax rate at present. However, there's large fee lowering space, such as keeping decreasing social security charges and clearing charges of complicated items. It is estimated that the tax reducing and fee lowering scale of 2017 will exceed CNY 700 billion. "Bolstering areas of weakness" will enter the implementation stage. In the first quarter of 2017, the investment of ecological protection and environmental governance sector, public facility management sector, agriculture sector and water conservancy management sector increased by 48.1%, 27.4%, 24.6% and 18.3% respectively, which was higher than the total investment for 38.9%, 18.2%, 15.4% and 9.1% respectively.

Development trends of key sectors

In the next few years, the development of a scientific and technological innovation center with global influence and a place of origin of important strategic emerging industries in China will be accelerated in Beijing. Adhere to high-end development direction, strengthen technological retrofit efforts, enhance industrial matching ability and pay attention to developing high-end modern manufacturing industry. Conform to industry integration and development law, actively promote deep integration of industrialization and informatization, stimulate extension of manufacturing industrial chain towards upstream and downstream, and improve the overall development quality of manufacturing industry. Take developing strategic emerging industries as the priority among priorities for promoting the development of modern manufacturing industry, scientific, strengthening the research and development of key, core and advanced technologies based on the technological and intellectual resources and industrial base of capital, focus on driving the development of new generation of information technology, new energy vehicle, energy conservation and environmental protection, high-end equipment manufacturing, biological medicine, new energy, new material and aerospace industry, etc., establish Beijing Economic-Technological Development Area, build "Created in Beijing" brand, occupy high end of industrial development, and strive to make strategic emerging industries the forerunner and pillar industries of the capital's economy. Automobile manufacturing industry is still an important driving force for the economic development of Beijing. The automobile manufacturing industry of Tongzhou and Shunyi regions will keep fast development. The traditional sectors and petroleum processing sector, etc. of Fangshan District will keep steady growth. Tertiary industry represented by tourism and financial industries will enter a new round of fast development period during the period of 13th Five-Year Plan. The development vein of financial industry of Fengtai and Chaoyang districts, etc. has been planned in detail. A series of actions, such as Lize Financial Business District and eastern expansion of CBD will improve financial industry's status in the economy of Beijing steadily.

The iron and steel sector of Tianjin was affected by the capacity policy of last year, the iron and steel capacity of pressure-reducing jurisdiction was 3.19 million tons in 2016, and the planned steel capacity of pressure-reducing jurisdiction is 1.8 million tons in 2017. Although it is expected that the good trend of domestic steel price will continue, the iron and steel enterprises of Tianjin still face problems like financing difficulties. On the whole, it is still hard to say that iron and steel sector has rebounded. The chemical sector of Tianjin is still under great pressure. First, the contradiction of excess capacity is prominent. The structural capacity surplus problem of traditional chemical sector is still severe due to serious excess in the past and weak demand for traditional bulk chemical products. Second, increase of environmental constraint pressure. Dagu & Botian relocation reconstruction project of Tianjin has great negative influence to the product production of chemical sector. Third, continued depression of external environment. Since the basic situation of excess of supply over demand of crude oil, chemical sector is subject to continued depression of external environment and great downward pressure.

The iron and steel consumption of Hebei has entered peak period when the capacity of low-end products is excess, and iron and steel sector is facing serious demand decline. In 2017, Hebei Province will keep cutting iron and steel capacity, and the overall sector development will still be in contraction state. It is estimated that iron and steel sector will face double challenges on optimizing product structure and industrial energy saving and efficiency improving in 2017, enterprises' management situation will still be severe, which will accelerate recombination and integration of enterprises further. Macro environment has great influence on the equipment manufacturing industry of Hebei. In 2016, its demand exceeded supply owing to cost reduction caused by drop of oil price, and the potential demand space of the market exceeded expectation. In 2017, the development of equipment manufacturing industry will be subject to positive factors from various aspects, such as increase of inner impetus, price rebound and various fostering policies, which will drive steady development of the whole sector. In 2016, the petrochemical sector of Hebei was featured by "growth rate slowdown, steady development and low-price running". With the gradual execution of steady growth macro policy and the promotion of cutting overcapacity and structural adjustment of the sector, the output value of petrochemical sector is expected to see steady growth in 2017. In 2016, the building material sector of Hebei grew steadily owing to multiple factors, such as regional real estate recovery, continuous increase of infrastructure construction projects (e.g. road and bridge), continuous operation of environmental protection equipment and brief price rally of iron and steel sector. In 2017, the estimated output of cement and plate glass will decrease by about 3%, and the production of sanitary ceramics and architectural ceramics will increase by about 6% on year-on-year basis due to impact from multiple factors, such as policy regulation, industrial transferring and upgrading and rising of labor price.

System and mechanism reform process

In November 2014, the State Council issued *Energy Development Strategic Action Plan* and put forward the strategic guideline of sticking to "saving, clean and safe" and focusing on the implementation of four strategies, i.e. more efficient, self-sufficient, green low-carbon and innovation driven, so as to accelerate the building of a clean, efficient, safe and sustainable modern energy system. In November 2017, National Development and Reform Commission issued *Energy Production and Consumption Revolution Strategy (2016-2030)*, which requires fully implementing energy revolution system layout by 2020, promoting clean fossil fuel, changing the extensive growth mode of energy consumption fundamentally and laying equal stress on policy orientation and restraint. For a long time, coal is the energy most consumed in JJJ with extensive utilization. Beijing is the core of JJJ, whose power and heat load demand grows significantly. Zhangjiakou of Hebei Province is adjacent to Beijing, which has rich wind energy resource. The differences in demands and resources among provinces and cities in JJJ create preconditions for the energy structrual adjustment of JJJ. Furthermore, the proposal of many energy reform policies has puts forward higher requirements for the green energy development of JJJ. In the meantime, fog and haze control and prevention in JJJ has been further strengthened since the release of the new *Environment Protection Law*. Energy transformation of JJJ is imminent.

In March 2015, the State Council issued *Several Opinions of the CPC Central Committee and the State Council on Further Deepening the Reform of the Electric Power System*. In March 2016, National Development and Reform Commission issued *Circular on Relevant Matters Regarding Expanding Power Transmission and Distribution Prices Reform Pilot Scope*, which clarified the key points and route of deepening the reform of electric power system: release the electricity prices in competitive areas excluding power transmission and distribution, release power generation and utilization plans excluding public beneficial and regulatory ones and release power distribution and selling businesses to social capital in an orderly manner based on the institutional framework of controlling the middle and releasing both ends; promote relatively independent and standardized operation of trading institutions; deepen research on regional power grid construction as well as power transmission and distribution system suitable to Chinese conditions further; strengthen government regulation, overall planning, safe and efficient operation as well as reliable supply of power further. In 2016, *Comprehensive Pilot Program on the Reform of Electric Power System of Tianjin* and *Reform Pilot Program for the Electric Power-retailing Side of Hebei Province* were approved. It is in the process for approval for piloting direct trading with major consumers, pricing of power transmission and distribution and reform of incremental power distribution service, etc. The reform of electric power system of JJJ has entered a new development stage.

The uncertainties in the safe and stable operation of power grid increase with the promotion of reform, and it is necessary to re-define responsibilities and obligations of the Government, power generation enterprises, power grid enterprises, power-retailing companies, consumers and various other entities to secure the safe operation. The safety of large power grid will face severe test. Power grid safety should be prioritized in electricity trading. With the promotion of reform, annual generation plan is being squeezed gradually, and companies need to arrange power grid operating mode based on market trading, which brings adverse impact to the balance of electricity supply and demand and optimization of load curve of power grid. If power grid transmission capacity is not well considered in the energy trading, it may cause power grid congestion with the increase of various trading proportions and put forward new challenges to the safe and stable operation of power system. In addition, higher requirements are proposed for the peak regulation and power ramping abilities, etc., of power system with the continuous increase of penetration levels of renewable energy, such as wind power and solar power. Moreover, large access of distributed new power will change the form of distribution network. Furthermore, the risk of reverse power flow and other accidents will rise with the rapid increase of power input nodes introduced by a large amount of distributed renewable sources, and it may change how distribution grid is currently operated.

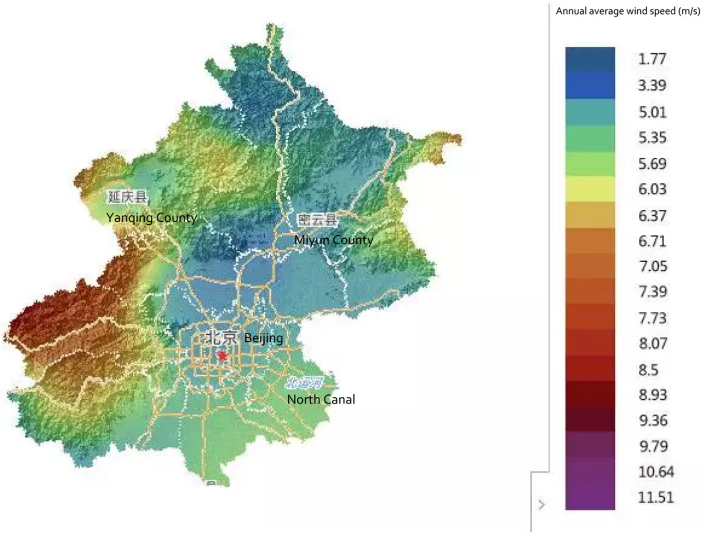
22.2 Outlook of Renewable Energy Development in JJJ

Resource Guarantee

Beijing

Beijing has a small area whose wind direction has obvious seasonal characteristic. Its wind energy resource rich areas are dispersed, most of which lie in northwestern and northern mountainous area. Besides, it has relatively small wind resource and tense construction land for wind farm. According to onshore wind energy resource evaluation results of China Meteorological Administration in 2014, the technical exploitation amount of wind energy resource in the height level of 70m and 100m from the ground in the area with a wind power density great than or equal to 200 w/m^2 in Beijing is 3.13GW and 3.42GW respectively.

Figure22-12 Wind Resource Map of Beijing



Beijing is solar energy resource rich area (Class 2) superior to Shanghai, Yunnan, Jiangsu and Zhejiang, etc. with annual radiation about 5,061×MJ/m^2 and annual sunshine duration of 2,761 hours. Its plain area is 6,390km^2, which receives solar radiation equivalent to 1.223 billion tons of coal equivalent every year, and its mountainous area is 10,418km^2, which receives solar radiation equivalent to 1.994 billion tons of coal equivalent every year. And the solar radiation of the whole city is equivalent to 3.217 billion tons of coal equivalent every year. Districts and counties in ecological conservation area, such as Yanqing, Miyun, Huairou and Yizhuang have the most superior solar energy resource.

The biomass resource of Beijing mainly includes crop straw, processing residues of agricultural products, trimmed branches of fruit trees, urban wood residues and livestock manure. Crop straw mainly consists of corn straw and wheat straw, whose theoretical potentiality is 1,458,200 tons and 300,000 tons respectively, accounting for 93.66% of total resources. Processing residues of agricultural products mainly are corn cob with theoretical resources of 226,000 tons and a small quantity of peanut shell with theoretical resources of 6,400 tons. Trimmed branches of fruit trees are mainly distributed in fruit tree areas, and the theoretical potentiality of Pinggu and Daxing accounts for 40% of total resources of the whole city. Urban wood residues are relatively rich, which mainly include urban greening trimmed branches, building residues and wood processing residues, whose theoretical potentiality is 602,200 tons, 225,100 tons and 72,000 tons respectively. Livestock manure mainly consists of pig manure, cattle manure and chicken manure, whose theoretical potentiality is 3,638,100 tons, 2,928,400 tons and 854,700 tons respectively. Beijing pays much attention and input to the development and utilization of biomass energy. Especially "three promotions" project (generalize solar energy street lamp, etc. to light up rural area; generalize energy-efficient housing insulation retrofit, etc. to warm up peasants; implement large and medium-scale biomass energy utilization projects, such as biogas and household biogas digester to circulate agricultural resources) implemented in suburb of Beijing since 2006 accelerates the development of biomass energy industry.

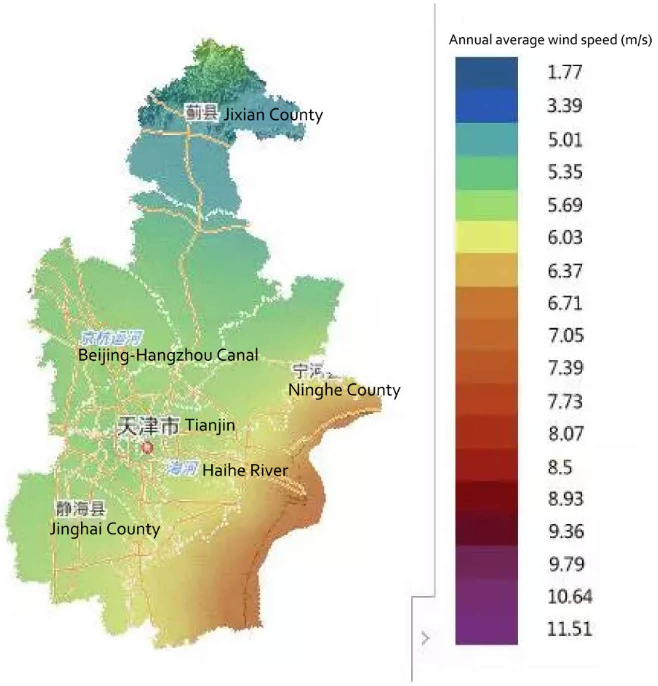
Tianjin

The wind energy resource distribution characteristic in Tianjin is rich in coastal region and poor in inland region. South-central area is subject to small wind speed and restricted by built-up areas and cultivated lands with relatively poor development and utilization conditions of wind energy resource. Partial of northern mountainous area has rich wind energy resource, but its development and utilization is limited to some extent due to high development and maintenance cost on mountain land. Eastern coastal region, especially the area along the western coastline of Bohai Sea has a high annual average wind power density and rich wind energy resource, which is suitable for scaled development and utilization. According to onshore wind energy resource evaluation results of China Meteorological Administration in 2014, the technical exploitation amount of wind energy resource in the height level of 70m and 100m from the ground in the area with a wind power density great than or equal to 200 w/m^2 in Tianjin is 920MW and 1.15GW respectively.

In general, Tianjin has rich solar energy resources, and it is Class 3 area based on solar energy resource distribution. Its average total solar radiation in 30 years is 5,966MJ/m^2, and the sunshine duration is 2,471~2,769 hours. Sunshine duration reduces from southeast to northwest, Tanggu region has the longest sunshine duration, while the urban area of Tianjin has the shortest sunshine duration.

Tianjin has good geothermal resource conditions. At present, Tianjin is striving to develop ground source heat pump system and encouraging clean retrofit of coal-fired (oil-fired) boiler by heat pump system to promote the replacement and upgrading of energy system.

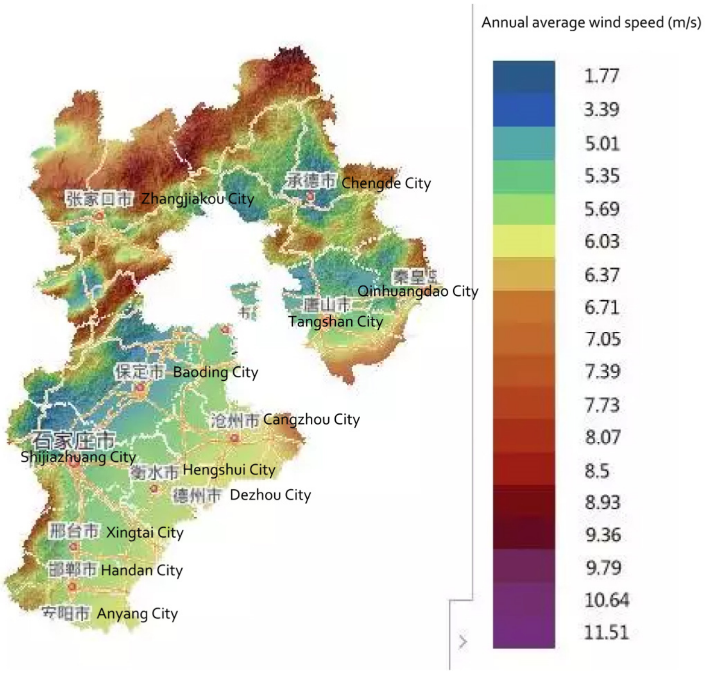
Figure 22-13 Wind Resource Map of Tianjin



Hebei

Hebei Province lies in middle latitude, east coast of Eurasian continent and eastern coastal region of China. It belongs to semi-humid and semi-arid continental monsoon climate of medium latitudes with rich wind energy resources and a technical exploitation amount over 80GW. Among them, onshore technical exploitation amount exceeds 70GW, and offshore technical exploitation amount exceeds 10GW, which is mainly distributed in Zhangjiakou, Chengde Bashang region, Qinhuangdao, Tangshan, coastal region of Cangzhou, Tai-hang Mountains and Yanshan mountainous area.

Figure22-14 Wind Resource Map of Hebei



Hebei Province is in a solar energy resource relatively rich zone of China, next only to Qinghai-Tibet Region and Northwest Region. Its annual radiation is 4,981-5,966MJ/m^2, and the exploitation amount of the whole province is about 90GW. The annual average sunshine duration of Zhangjiakou and Chengde in northern Hebei is 3,000-3,200 hours, and that in the mid-east region is 2,200-3,000 hours, which is Class 2 and Class 3 solar energy resource areas respectively. It has great development potentials for various forms, such as utility-scale power station, agriculture-solar complementary power generation and building integrated photovoltaic.

Hebei Province is a major agricultural province with rich biomass resources. Its annual production of crop straw is over 61.76 million tons. Except utilized straw, such as fuel wood, straw returning to the field, breeding straw, and papermaking straw, there is still 10.46 million tons can be used for energy processing. Utilizable amount of various resources: "three residues" of forestry (logging residue, bucking residue and processing residue): 5.7 million tons; residue of mushroom medium: 1.3 million tons; resources can be used for energy purpose such as a small number of caragana microphylls and livestock manure of Bashang and Pingyuan regions: about 20 million tons.

Hebei Province a wide geothermal energy storage area, which is mainly of medium and low temperature types and buried relatively shallow. It is mainly distributed in the folded zones of Yanshan Mountain and Tai-hang Mountains, intermountain fault basins of Yuxian County-Yangyuan, Zhaochuan and Huailai, as well as subsidence zones of Hebei Plain. Its annual shallow geothermal energy resource amounts to 285 million tons of coal equivalent, and the annual utilizable resource amounts to about 11 million tons of coal equivalent. Its medium-deep geothermal energy resource amounts to 23.52 billion tons of coal equivalent, and the recoverable heat resource amounts to 4.97 billion tons of coal equivalent.

Hebei Province has limited exploitable and utilizable hydropower resources. However, since the water is flowing to plain from mountainous area featured by great change in river bed gradient, steep slope and turbulent flow, it has development condition for pumped storage power station, and the exploitable amount of pumped storage power station is over 16GW approximately.

Policy Environment

JJJ has issued several policy papers on promoting renewable energy development since 2000, as shown below:

Table22-7 Policy Papers on Renewable Energy Development

Issued by	Name
Country	Renewable Energy Law of the People's Republic of China
	Detailed Rules for the Implementation of Grid-connected Operation and Management of Photovoltaic (PV) Power Plants in North China (Trial)
Beijing	13th FYP Energy Development Plan of Beijing
	13th FYP Development Plan of New and Renewable Energy
	Clean Air Action Plan of Beijing (2013~2017)
	Guidance of Beijing on Accelerating the Exploitation and Utilization on Solar Energy to Promote Industrial Development in Beijing
	Interim Measures of Beijing for Management of Distributed Photovoltaic Power Generation Projects
	Management Measures of Beijing on Reward Funds for Distributed Photovoltaic Power Generation Projects
	Management Measures of Beijing for Application of Solar Water Heating System on Urban Buildings
	Opinions on Policies of Improving "Coal to Electricity" and "Coal to Gas" for Urban Residents in Beijing
	Opinions on Strengthening Geothermal Energy Development and Heat Pump System Utilization
	2017 Implementation Plan for "Coal to Clean Energy" and "Coal Reduction and Replacement" in Rural Areas and Villages of Beijing
Tianjin	13th FYP Development Plan of Tianjin for Renewable Energy
Hebei	13th FYP Development Plan of Hebei Province for Renewable Energy
	Self-disciplinary Convention of Renewable Energy Industry Association of Hebei Province

Scenario Setting

Under current environment and resource limitations, the Central Government emphasizes on promoting the supply-side structural reform, developing energy development strategy and decision and energy development pathway with faster development of clean energy and prudent development of fossil fuel as dominant ideas, researching 13th FYP energy planning objectives in JJJ and 2030 Energy Development Strategy with "Creating Beautiful China by 2050" as the consensus, fully considering restriction factors of renewable energy development during system reform deepening, and setting a rational development scenario. As end energy increasingly depends on electricity, electricity development in JJJ plays an increasingly significant role in energy transformation. Therefore, Stated Policies Scenario and 2°C scenario are also set for research in JJJ.

Development Prospect

Economic development

In 2017, Beijing's GDP is expected to grow by about 6.5%; general public budget revenues will grow by 6.5%; the rise in CPI will be held around 3.5%; the registered urban unemployment rate will be controlled below 3%; the increase of per capita disposable income of urban and rural residents keeps pace with economic growth; energy consumption and carbon dioxide emissions per CNY 10,000 of GDP will be decreased by 3.5% and 4% respectively; water consumption per CNY 10,000 of GDP will be decreased by about 3%; and Beijing will strive for controlling the concentrations of fine particles below about 60ug/m^3.

In 2017, Tianjin's GDP is expected to grow by 8%; general public budget revenues will grow by 10%; the fixed assets investment will increase by 10%; total retail sales of social consumer goods will increase by about 8%; the registered urban unemployment rate will be controlled below 3.8%; the per capita disposable income of residents will increase by 8%; the rise in CPI will be held around 3%; the annual objectives of energy conservation and emission reduction will be achieved.

In 2017, Hebei's GDP is expected to grow by 7%; local general public budget revenues will grow by 7%; the fixed assets investment will increase by about 9%; total retail sales of social consumer goods will increase by about 10%; foreign trade export will present a steady rise; PM2.5 average concentration will be decreased by more than 6%; energy consumption per unit of GDP will decrease by about 4%; tasks regarding COD, sulphur-dioxide, ammonia-nitrogen and nitrogen oxide emission reduction delivered by the State will be completed; per capita disposable income of residents in whole province will increase by about 8%; the rise in CPI will be held around 3%; and the registered urban unemployment rate will be controlled below 4.5%.

Power demand

Provinces and cities in JJJ will realize the industrialization by 2020, and sharp slowdown in industrial growth will lead to further reduction of power demand. However, under the drive by the tertiary industry and rapid growth in electricity consumption by urban and rural residents, the power demand in JJJ will present a fast growth. Under the Stated Policies Scenario, total electricity consumption in Beijing will reach about 96TWh and 114TWh by 2020 and 2030 respectively; total electricity consumption in Tianjin will reach 80TWh and 109TWh by 2020 and 2030 respectively; and total electricity consumption in Hebei Province will reach 349TWh and 443TWh by 2020 and 2030 respectively. Under Below 2°C Scenario, total electricity consumption in JJJ will be increased, in which total electricity consumption in Beijing will reach about 98TWh and 122TWh by 2020 and 2030 respectively; that in Tianjin will reach 81TWh and 117TWh by 2020 and 2030 respectively; and that in Hebei will reach 354TWh and 477TWh respectively.

Table 22-8 Power demand in JJJ by 2020 and 2030

Province (City)	Total electricity consumption by 2020 (TWh)		Total electricity consumption by 2030 (TWh)	
	Stated Policies Scenario	Below 2°C Scenario	Stated Policies Scenario	Below 2°C Scenario
Beijing	96	98	114	122
Tianjin	80	81	109	117
Hebei	349	354	443	477

Power supply

(1)Coal power

Viewed from installed capacity, under the Stated Policies Scenario, the coal-fired power installed capacity in JJJ will reach 56.2GW and42.5GW by 2020 and 2030 respectively in a decline, and accounts for 51.1% and 25.5% of the total installed power capacity respectively. Under Below 2°C Scenario, with rapid development of such renewable energy as wind power and solar energy, the coal-fired power installed capacity in JJJ will reach57.8GW and 43.5GW in a slight increase by 2020 and 2030, in which the proportion of coal power to total installed electricity capacity will have a sharp decline after 2020, and will be decreased to 16.2% by 2030.

Viewed from power generation, under the Stated Policies Scenario, annual coal-fired power generation will reach 234TWh and 194TWh by 2020 and 2030 respectively; the cumulative utilization hours will reach 4163h and 4554h by 2020 and 2030 respectively. Under Below 2°C Scenario, annual coal-fired power generation in JJJ will reach 193TWh and 156TWh by 2020 and 2030 respectively in a further decline; the cumulative utilization hours will reach 3342h and 3595h by 2020 and 2030 respectively.

Viewed from the layout of generation capacity, coal-fired power generation units fade out in Beijing, and will be mainly distributed in Hebei Province. Through comparison under these two scenarios, with the rapid development of wind and solar energy, installed capacity of coal-fired plants will have a slight increase demanded by higher need of regulating capacity of the power system under Below 2°C Scenario in Tianjin and Hebei.

Table 22-9 Installed generating capacity in Beijing-Tianjin-Hebei by 2020

Province (City)	Stated Policies Scenario (MW)						Below 2°C Scenario (MW)					
	Hydropower	Coal power	Gas Power	Wind power	Solar energy	Biomass	Hydropower	Coal power	Gas Power	Wind power	Solar energy	Biomass
Beijing	980	0	7947	386	923	224	980	0	7947	386	981	364
Tianjin	5	9934	4415	1516	1399	130	5	11072	4415	1516	1399	146
Hebei	550	46269	62	23267	10183	1,647	550	46774	62	32959	12008	1738

Table 22-1 Installed generating capacity in Beijing-Tianjin-Hebei by 2030

Province (City)	Stated Policies Scenario (MW)						Below 2°C Scenario (MW)					
	Hydropower	Coal power	Gas Power	Wind power	Solar energy	Biomass	Hydropower	Coal power	Gas Power	Wind power	Solar energy	Biomass
Beijing	980	0	5,298	386	2,910	450	980	0	5,298	386	10,000	373
Tianjin	5	11,115	2,943	1,616	1,978	225	5	11115	2,943	1,616	5,270	225
Hebei	550	31,400	174	73,082	31,780	1,866	550	32414	42	126,163	68,652	1,869

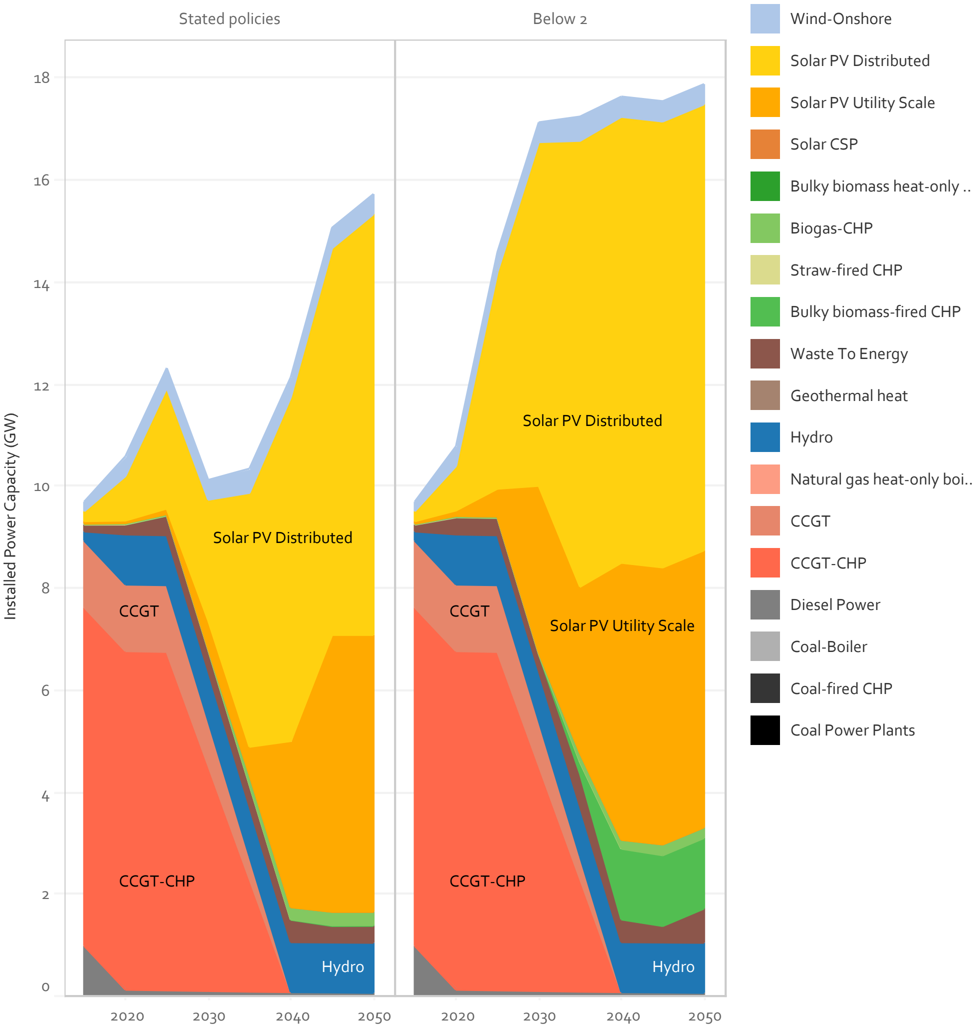
(2)Gas Power

Viewed from installed capacity, under the Stated Policies Scenario, the gas-fired power installed capacity in JJJ will reach 12.424GW and 8.415GW by 2020 and 2030 respectively in a decline, and accounts for 11.3% and 5.0% of the total installed power capacity respectively. Under Below 2°C Scenario, to meet the demand for system heating and peak regulation, the gas-fired power installed capacity in JJJ will present less change compared with that under the Stated Policies Scenario, and the installed capacity will reach 12.424GW and 8.283GW by 2020 and 2030 respectively. However, the proportion of gas power to the total installed power capacity will have a sharp decline after 2020, and will be decreased to 3.1% by 2030.

Viewed from power generation, under the Stated Policies Scenario, annual gas-fired power generation in JJJ will reach 19.62TWh and 635TWh by 2020 and 2030 respectively; the cumulative utilization hours will reach 1,579h and 75h by 2020 and 2030 respectively. Under Below 2°C Scenario, annual gas-fired power generation will reach 19.62TWh and 1.131TWh by 2020 and 2030 respectively; the cumulative utilization hours will reach 1,579 and 137 by 2020 and 2030 respectively.

Viewed from the layout, the gas-fired power installed capacity will be mainly concentrated in Beijing and Tianjin, in which gas power in Beijing and Tianjin accounts for more than 99% of total installed capacity of gas power plants in JJJ. According to environment constraints and peak regulation demands, the installed capacity of gas power plants in JJJ presents less change under these two scenarios.

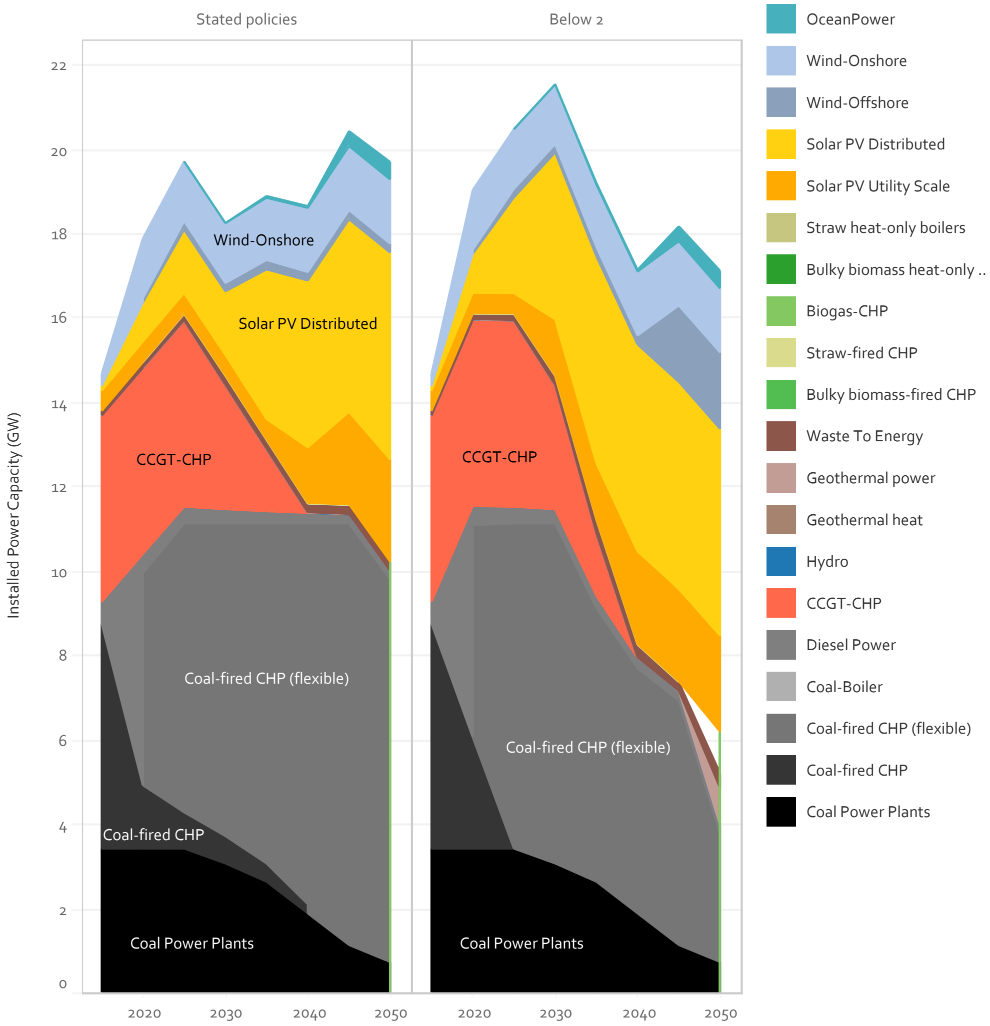
Figure 22-15 Installed Capacity in Beijing (GW) (by power generation type)



(3)Wind power

Viewed from installed capacity, under the Stated Policies Scenario, the wind power installed capacity in JJJ will reach 25.168GW and 75.084GW by 2020 and 2030 respectively, and accounts for 22.9% and 45.0% of the total installed power capacity respectively. Under Below 2°C Scenariobefore 2020, through the construction of transmission capacity and development of more flexible power system, together with technical breakthroughs and lowed cost, the installed capacity of wind power plants will be 34.860GW; in 2020-2030, wind power in JJJ will continue its rapidly growthwith completely deepening the electricity system reform; by 2030, the wind power installed capacity will reach 128.165GW, and will account for 47.8% of total power installed capacity, with onshore wind power taking up the main part, supplemented by offshore (including intertidal zone) wind power.

Figure 22-16 Installed Capacity in Tianjin (GW) (by power generation type)



Viewed from power generation, under the Stated Policies Scenario, annual wind power generation in JJJ will reach 66.314TWh and 210.649TWh by 2020 and 2030 respectively; the cumulative utilization hours will reach 2,635h and 2,806h by 2020 and 2030 respectively. Under Below2°CScenario, annual wind power generation will reach 96.543TWh and 356.314TWh by 2020 and 2030 respectively; the cumulative utilization hours will reach 2,769 and 2,780 by 2020 and 2030 respectively.

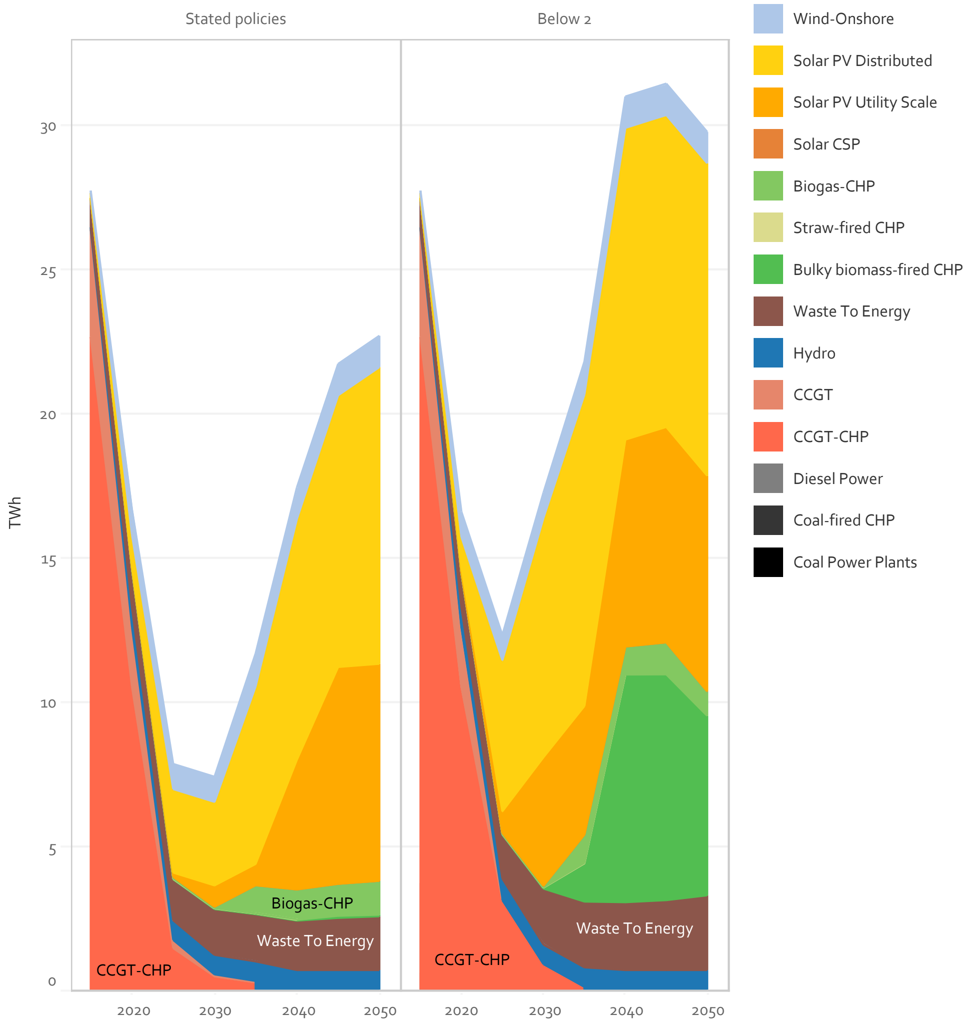
Seen from the layout, under resource restraints, wind power installed capacity in JJJ will be mainly concentrated in Hebei Province. Through comparison of these two scenarios, the wind power installed capacity will present less change in Beijing and Tianjin, but that in Hebei will have a great increase. The wind power installed capacity will reach 126.163GW by 2030 under rapid development, accounting for about 98% of total installed capacity of wind power plants in JJJ.

(4)Solar energy

Viewed from the installed capacity, with the reduction in cost of PV power generation and the implementation of target guiding system for the development of renewable energy and management measures of full-amount guaranteed purchase of electricity under the Stated Policies Scenario, solar power in JJJ will keep a stable growth. By 2020, the total solar power installed capacity will reach 12505GW, accounting for 1.4% of the total power installed capacity, and the power generation will reach 16.132TWh; by 2030, the total solar power installed capacity will reach 36.668GW, accounting for 22.0% of the total power installed capacity, and the generating capacity will reach 48.258TWh. Under Below2°CScenario, by 2020, the solar power installed capacity in JJJ will be 14.388GW, accounting for 1.7% of the total power installed capacity, and the generating capacity will reach 1873.9TWh; by 2030, the total solar power installed capacity will reach 83.922GW, accounting for 31.3% of the total power installed capacity, and the power generation will hopefully reach 116.791TWh through maximum development and utilization of solar power depending on resources potentials.

Viewed from the layout, JJJ have a good potential in solar energy resources. Through comparison under these two scenarios, the solar power installed capacity will present less change in Beijing and Tianjin before 2020; the solar power installed capacity will present a great growth in provinces and cities of JJJ, and the installed capacity of Beijing, Tianjin and Hebei Province will reach 10GW, 5.27GW and 68.652GW respectively in 2030.

Figure 22-17 Power Generation in Beijing (TWh) (by power generation type)



(5)Biomass

Viewed from installed capacity, under the Stated Policies Scenario, with the reduction in the cost of biomass power generation and improvement of urbanization level, biomass power in JJJ will continuously keep a stable growth. The biomass power installed capacity will reach 2.001GW and 2.542GW by 2020 and 2030 respectively, accounting for 1.8%and 1.5% of total electricity installed capacity respectively. Under Below 2°C Scenario, the biomass power installed capacity of JJJ will present less change compared with the Stated Policies Scenario by 2020 and 2030, and will reach 2.248GWand 2.467GW respectively, accounting for 1.8% and 0.9% of total electricity installed capacity respectively.

Viewed from power generation, under the Stated Policies Scenario, annual biomass-fired power generation in JJJ will reach 9.311TWh and 11.031TWh by 2020 and 2030 respectively; the cumulative utilization hours will reach 4653h and44340h by 2020 and 2030 respectively. Under Below2°CScenario, annual biomass-fired power generation will reach 9.568TWh and 12.907TWh by 2020 and 2030 respectively; the cumulative utilization hours will reach 4256h and 5231h by 2020 and 2030respectively.

Viewed from the layout, biomass-fired power installed capacity will be mainly concentrated in Beijing and Hebei Province. Under resource restrictions, the biomass-fired power installed capacity in JJJ will present less change under these two scenarios.

Power energy exchange scale

Under the Stated Policies Scenario, by 2020 and 2030, JJJ will still receive electricity from power grids of other regions, in which the net electricity input in Beijing will reach 96TWh and 128TWh respectively; the net electricity input in Tianjin will reach 35TWh and 64TWhrespectively; and the net electricity input in Hebei Province will reach 78TWh and 53TWh respectively. Under Below2°CScenario, by 2020, JJJ Region will still receive electricity from other regions. With the development of renewable energy, the electricity input of Beijing and Tianjin will have a decline, in which the net electricity input in Beijing will reach 86TWh; the net electricity input in Tianjin will reach 32TWh; and the net electricity input in Hebei Province will increase to 95TWh; by 2030, with rapid expansion of renewable energy, Hebei will take the lead to reach a balance of energy production and consumptionand start to output electricity. Its net electricity output will reach 77TWh. With limited resource, Beijing and Tianjin will still receive electricity from power grids of other regions, and the net electricity input will reach 122TWh and 72TWh respectively.

Figure22-18 Power Energy Exchange in JJJ by 2020

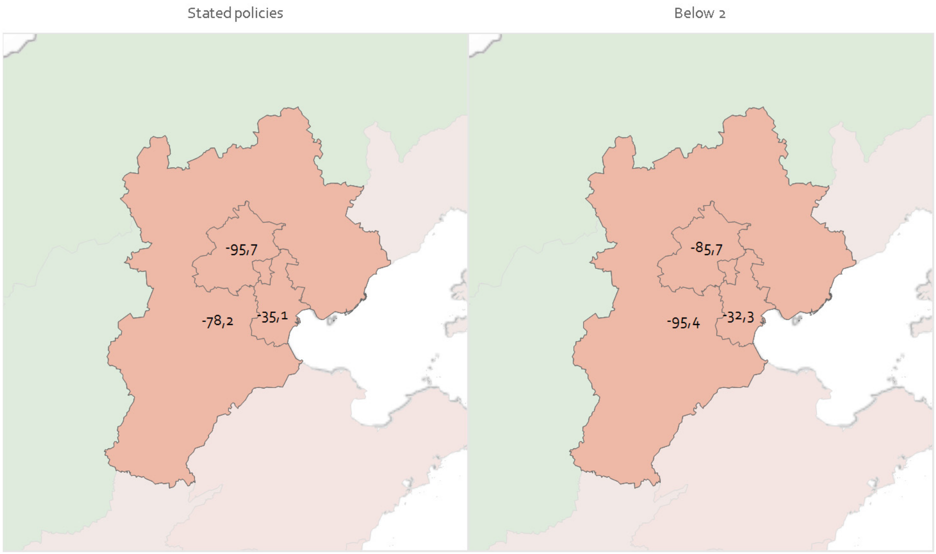
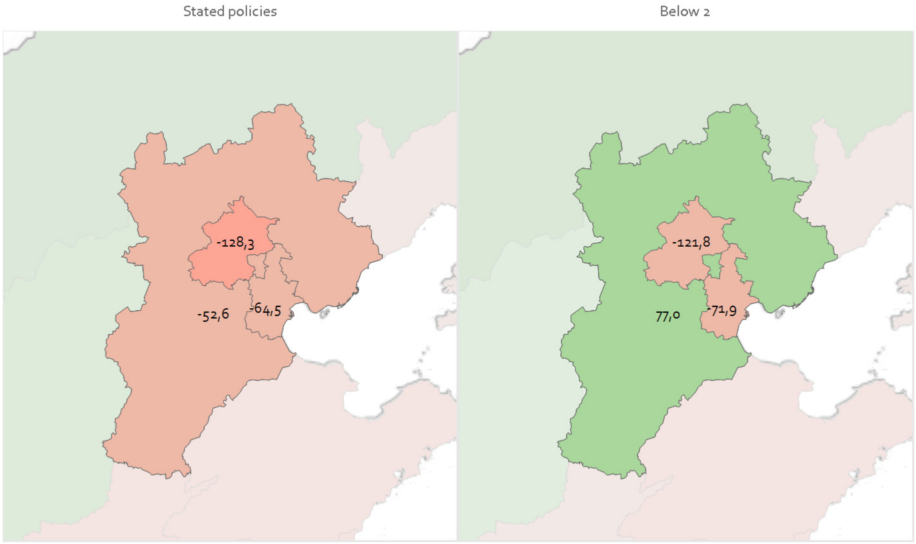


Figure 22-19 Power Energy Exchange in JJJ by 2030



Viewed from power energy exchange, Beijing will mainly receive electricity from Hebei Province and Shanxi Province; Tianjin will mainly receive electricity from Hebei Province and Inner Mongolia; Hebei Province will exchange electricity with Beijing, Henan Province, Inner Mongolia, Liaoning Province, Shandong Province, Shanxi Province and Tianjin.

Figure 22-20 Power Energy Exchange between Beijing and Surrounding Provinces and Cities

Figure 22-21 Power Energy Exchange between Tianjin and Surrounding Provinces and Cities

Figure 22-22 Power Energy Exchange between Hebei Province and Surrounding Provinces and Cities

Green energy development in Xiong'an New AreaArea

Xiong'an New Area is located in Baoding City, Hebei Province in the hinterland of Beijing, Tianjin and Baoding. On April 1, 2017, the CPC Central Committee and the State Council decided to set up a national-level new area in Baoding City, which was a new area with national significance followed by Shenzhen Special Economic Zone and Shanghai Pudong New Area. Setup of Xiong'an New Area will bring great practical significance and far-reaching historic significance in distributing non-capital functions of Beijing in a centralized manner, exploring densely populated areas, optimizing and developing the new mode, adjusting and optimizing the urban layout and space structure of JJJ, fostering innovation drive and developing a new engine.

Figure 22-23 Geographic Location of Xiong'an New Area

Xiong'an New Area plans to firstly develop the particular areas as the start areas, with an area of about 100km^2; in addition, the development area will have an area of about 200km^2 in the medium term, and the control area will have an area of about 2,000km^2 in the long term. Xiong'an New Area will be developed into a second-tier large city, and will complete following 7 key tasks during planning and construction: 1. build a world-class, green, modern and smart city; 2. become a city with scenic ecological environment, blue skies, fresh air and clean water; 3. develop high-end innovative industries and actively attracting and gather innovative factor resources as new growth engines; 4. Provide quality public services, constructing high-quality public facilities, and creating a new urban management model; 5. establish a fast and effective green transportation network, and creating a green transportation system; 6. deepen system and mechanism reforms, and play a decisive role of the market in resource allocation and play the role of the Government in a better way so as to stimulate market vitality; 7. Expand the multi-directional opening-up, and create a new highland for opening-up and new platform for foreign cooperation.

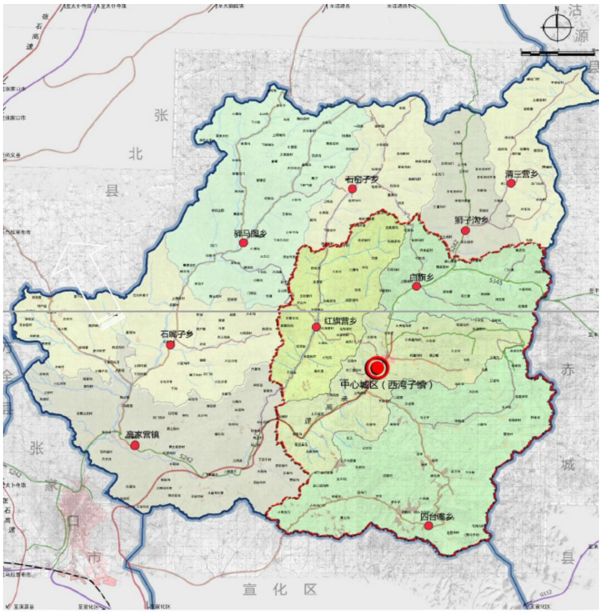
Several major tasks for construction of Xiong'an New Area are associated with green development, and green development has become an important mark for construction of Xiong'an New Area. The key for regional green development is energy selection. Xiong'an New Area has abundant energy resources, in which Xiongxian County has natural gas reserves of over 1 billion cubic meters and over 1,200 oil wells with annual crude oil output of 700,000 tons and natural gas output of 18 million cubic meters; the geothermal field has an area of 320km^2 with geothermal water reserves of 82.178 billion cubic meters. Anxin County has over 350km^2 of geothermal resources with the reserves of over 15 billion tons. Therefore, Xiong'an New Area constructs energy system with green & low-carbon, reliability & intelligence and economic performance and high-efficiency as the key so as to achieve high-proportion utilization of renewable energy. By taking full advantage of wind power and photovoltaic power from Zhangjiakou, Inner Mongolia and other surrounding regions, Xiong'an New Area will energetically develop the cascade utilization of deep and shallow geotherm, achieve the orderly development of local renewable energy such as distributed photovoltaic power generation and garbage power generation, construct an energy supply pattern with the external electricity and local geothermal energy taking up the main part, supplemented by such renewable energy as local solar energy and biomass energy and achieve the objective that renewable energy accounts for over 50% of primary energy consumption.

Green and low-carbon Olympic Games in Chongli District

The XXIV Olympic Winter Games will be held in China in 2022. It is the first time for China to hold the Winter Olympic Games in history. The Winter Olympic Games will be hosted in Beijing and Zhangjiakou, as the third Olympic event which is held in China, followed by Beijing Olympic Games and Nanjing Youth Olympic Games. For this, Zhangjiakou City proposes the idea of "Green Olympics, Low-carbon Olympics".

Chongli District (Zhangjiakou City), as the host venue of this Winter Olympic Games, will hold ski jumping, snowboarding, freestyle skiing, nordic skiing, biathlon and cross-country skiing competitions. Chongli District has abundant renewable energy resources such as wind and solar energy, and the wind energy reserves reach 239.58GWh, 2.09GWh of which is technically exploitable; Chongli District is a Class 2 solar energy resource area, and has high development and utilization value; in addition, Chongli District has abundant geothermal resources with outlet water temperature of 39-88℃. However, Chongli District has taken coal as the main energy for a long time, and heat is mostly supplied in a centralized manner. Chongli District has 2 coal-fired boilers (Xiaoxigou Heat Source Plant3*46 MW +Er'daogou Heat Source Plant2*58 MW) for centralized heating, with annual heat output of 254MW and total heating capacity of 370,000m^2. Therefore, according to the idea of "Green Olympics, Low-carbon Olympics", main energy of Chongli Olympic Games Area is almost completely renewable energy for near zero emission in the District.

Figure 22-24 Map of Chongli District



Chongli is currently planning two major energy platforms. The power platform will have a planned total capacity of 1.985GWh and annual power generation of 3.346TWh in 2022, in which wind power has a total planned capacity of 700MWh and photovoltaic power has a planned capacity of 1.285GWh. The heating platform includes construction of auxiliary facilities of the distribution network for electric heating, renewable energy heating projects for rural buildings and solar energy heating projects. For construction of Olympic venues, renewable energy power will become main power supply of the Olympic venues, and electricity from surrounding counties will become auxiliary power supply so as to achieve 100% electricity consumption depending on renewable energy in the Olympic Center and other venues; 4-6 large solar energy district heating stations with an area of 100,000m^2 will be constructed so that all buildings of the Olympic venues can achieve heating by renewable energy. In addition, a "Beijing-Zhangjiakou ecological and photovoltaic guest-meeting corridor" will be constructed along the G6 Highway to the site of Chongli Winter Olympic Games. In terms of the promotion of low-carbon municipal administration and transport, the energy supply mode combining centralized and distributed energy supply will be applied, and only renewable energy will be used for electricity and heat utilization in public areas, hospitals, schools, parks, squares and other public places. Not only that, only renewable energy will be used for heating in the Olympic Village, Chongli District center, main scenic areas and surrounding rural areas. Solar energy, geotherm and other green heat sources will be mainly used for heating in the Olympic Village and District center following the principle of centralized heating prioritized and distributed heating assisting. Distributed solar heating will be used in other areas.

22.3 Renewable Energy Action Plan in JJJ

Key Task

Realize the objective of green and low-carbon development in Olympic Games Area

Construct a green and low-carbon Olympic games area according to ideas and requirements of "Low-carbon Olympic" by completing following tasks: (1) Achieve a high proportion of renewable energy-based power supply. Rely on renewable energy power development advantages, take renewable energy power in the Olympic Games Area or surrounding areas as the main power supply of the Olympic Games Area for the nearest power supply, and take power grids of Chongli District and surrounding districts and counties as the support and supplement with large power grids; make coordination in construction of Olympic Games venues and auxiliary facilities, promotion of cleaning and heating, upgrade and expand the distribution network, and guarantee power supply reliability and power grid safety operation in the Olympic Games Area; rationally plan and erect various types of energy storage equipment, fully exploit the potential of manoeuvrable stored energy in the Olympic Games Area and flexible power supply or load in the multi-energy synergism and complement system, and improve the system flexibility and reliability. (2) Promote multi-purpose application of renewable energy. Promote wind power heating projects in the Olympic Games Area, energetically promote ground source heat pumps in rural areas and popularize solar heat utilization and other technologies in urban and rural areas through cross-seasonal centralized heat storage and wind power hydrogen production demonstration, give full play to the role of renewable energy in energy-use fields such as heating and transport, effectively mobilize flexibility of multi-energy synergism and complement system, and improve the renewable energy utilization efficiency; cooperate with Chongli District (Zhangjiakou) and Yanqing District (Beijing) in expanding wind power heating, promote the nearest consumption of wind power and increase the renewable energy utilization proportion. (3) Accelerate integration of green transportation, distributed energy and intelligent energy. Enhance the utilization of renewable energy in public transport (such as bus, taxi and sightseeing vehicle) in the Olympic Games Area, provide transport energy by using biomass fuel, hydrogen and electricity, rationally arrange charging facilities for electric vehicles, and make demand response by applying the intelligent charging technology; construct solar energy, wind energy, biomass energy and other distributed power supply in the Olympic Games Area according to local conditions, and achieve integrated power generation and consumption and narrower local consumption by applying micro-grid and other technologies; give priority to energy supply depending on renewable energy according to the mode with concentrated supply based and distributed supply supplemented, and construct energy-saving building in the forms of building energy saving and intelligent building, etc. (4) Implement system and mechanism innovation, and effectively play the role of market players. According to the spirits of the *Outline of the Coordinated Development Plan for the JJJ*, *Development Plan of Renewable Energy Demonstration Zone* in Zhangjiakou and other papers, perform early and pilot implementation and innovative demonstration, and explore the new mode and mechanism for accelerating renewable energy development; deepen the reform of power market mechanism, create sound and prejudice-free market competition mechanism, implement the trans-provincial or interregional transaction mechanism, rationally utilize flexibility of tariff mechanism-based mobility system, fully explore the value of stored energy, and restore the commodity property of energy.

Achieve a high proportion of renewable energy-based development in Xiong'an New Area

A high proportion of renewable energy development in Xiong'an New Area will focus on green & low carbon, reliability & intelligence, economic performance and high-efficiency so as to achieve the development objective of high-proportion utilization of renewable energy. (1) Adhere to the green development concept. As construction of Xiong'an New Area is related to millennium strategy and Xiong'an New Area is located in the hinterland of JJJ, we will lay emphasis on coordinated development of ecology and economy so as to leave a homeland with blue sky and clean water for next generations, horizontal coordination, incorporation of ecological civilization construction into "five-in-one" overall layout and integration of green development concept into energy development. (2) Make overall medium and long-term plans on various energy resources. Effectively coordinate and plan renewable energy and conventional fossil fuel in Xiong'an New Area, optimize high-efficiency utilization of various energy resources, especially strengthen the cohesion between district-level plan and provincial/national-level plan, improve the coverage, authoritativeness and scientificity of the plans, enhance the plan transparency and public participation, orderly organize the implementation of various energy development and layout in strict accordance with the plans; fully take resource environmental bearing-capacity into consideration, and perform planned environmental impact assessment by law; disclose the plans to the public upon review according to legal procedures; establish the working mechanism of inspection, supervision, evaluation and appraisal of the plans so as to guarantee the effective implementation of the plans. (3) Promote high-proportion innovative development of renewable energy in the New Area. Improve the system and mechanism for encouraging renewable energy development in Xiong'an New Area, break the bottleneck of existing system and mechanism; innovate the management concept, and strengthen trans-regional renewable energy-based power dispatching; increase scientific research investment, reduce the utilization cost of renewable energy, accelerate and promote the renewable energy connection to grid at an equal price, get rid of the dependence on subsidiary policies as soon as possible; it is urgent to make breakthroughs in supporting energy storage technologies for renewable energy and make major technical breakthroughs in cascade development and utilization of geothermal energy in Xiong'an New Area.

Realize coordinated development of renewable energy sources in JJJ

In light of differences in energy resources distribution and energy demand among the Beijing, Tianjin and Hebei regions, promoting efficient, reasonable and economical utilization of renewable energy sources in JJJ requires to: (1) Adhere to the principle of being green and low-carbon oriented to promote energy consumption and supply revolution. Control total energy and coal consumed in JJJ strictly; earnestly implement the scheme of coal consumption reduction and replacement to curtail coal consumption sharply; dig load characteristics in Beijing and Tianjin, make them match renewable energy power output in Hebei Province, so as to create energy internet in Hebei Province focusing on the renewable energy sources, realizing interconnection of electric power, user distribution and energy storage; give full play to the energy advantages in JJJ, to create new green power structure by centering on such renewable energy sources as wind energy, photovoltaic energy and optothermal energy, supplemented by clean energy including combined cooling, heating and power generation and biomass power generation, and regulated by storage measures such as pumped storage by south-to-north water diversion and energy storage by using new energy electric vehicles; realize energy exploitation, power distribution and transformation from traditional centralized mode to intelligent distributed mode, constructing energy sharing network among Beijing, Tianjin and Hebei regions. (2) Strengthen unified planning for renewable energy development in JJJ Strengthen overall arrangement for renewable energy development in JJJ; coordinate resource allocation and industrial policy measures in these three regions; strengthen communication on planning for renewable energy development in these three regions, to establish a plan about renewable energy development in JJJ from the aspects of resource allocation, policy guidance and balance between supply and demand; strengthen planning and construction of infrastructures for renewable energy supply like supporting power grid; make full use of resource advantages in such areas as Zhangjiakou, Hebei Province where it is abundant in renewable energy resources, to promote development of renewable energy like wind energy and light energy. (3) Improve the policy mechanism for coordinated development of renewable energy in JJJ Improve land policy for renewable energy sources, to provide supports for the development of renewable energy like wind energy and light energy; establish the competitive mechanism for the development of renewable energy power market, to make the renewable energy power to take initiatives in the future power market; establish the mechanism of distributed generation participation and distribution side electricity transaction; provide direct power supply service by distributed generation; improve the price system for heat supply by using the renewable energy; establish regional energy station heat supply system according to the new town and new rural reconstruction work by referring to the policy and price for distributed heating system by using natural gas; and constantly improve the price system for heat supply by using renewable energy.

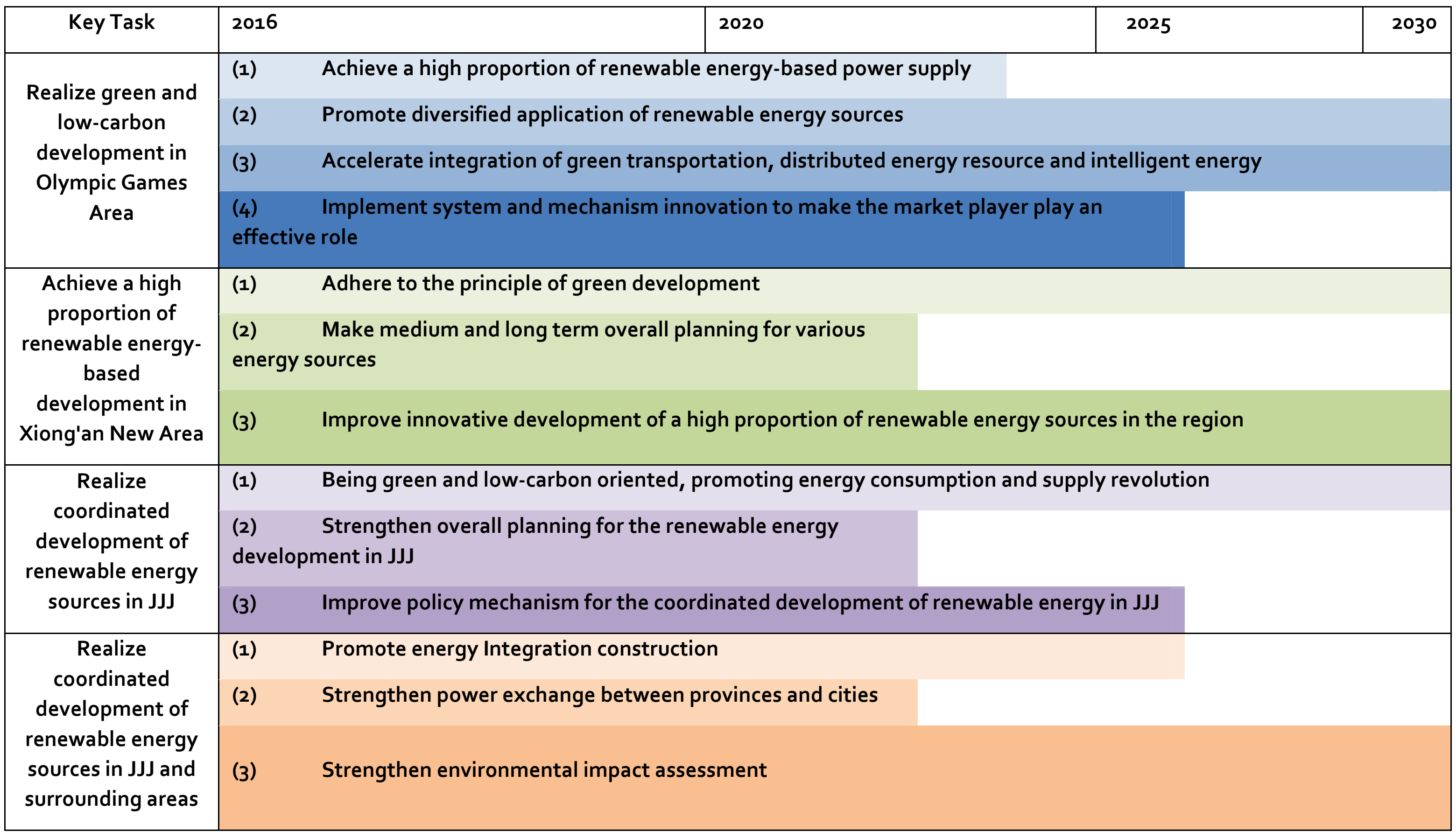
Realize coordinated development of renewable energy sources in JJJ and surrounding areas

The development of a high proportion of renewable energy sources in JJJ cannot be separated from the coordinated development in surrounding provinces and cities like Inner Mongolia, Shanxi and Henan provinces. It requires to: (1) Promote integrated energy construction. Perform longitudinal interfacing between the energy development planning and overall national energy planning, to place energy strategy in JJJ into the overall energy planning of the "13th Five-Year Plan" for overall consideration; make overall arrangements for the connection and balance between the coal, oil, gas and electricity in JJJ and the national energy strategy planning; perform transverse connection between JJJ and the Yangtze River Economic Zone, six provinces and autonomous regions in northwest China in the Silk Road Economic Belt; strengthen mutual complementation of energy advantages with major economic belts or economic circle outside the region; optimize spatiotemporal layout and give full play to the comparative advantage of coordinated development of JJJ in the energy field; strengthen the interconnection of energy infrastructure of JJJ and surrounding areas and horizontal collaboration in energy system structure optimization, to optimize the energy system and promote differentiated development and coordinated development. (2) Strengthen power exchange between provinces and cities. Deepen cooperation between JJJ and surrounding areas in the field of energy, propel green electric power in such provinces and cities as Inner Mongolia, where are abundant in energy to enter JJJ, to raise the proportion of electricity from renewable energy that can be transferred to other localities; accelerate and promote construction of power transmission channel between relevant provinces and cities; improve power grid architectures of all levels; and enhance the receiving capability for green electricity that can be transferred to other localities; encourage the construction of supporting power peak regulation and energy storage facilities, and gradually improve the regulation capability of the power system through improving the flexibility of the coal-fired generation unit and peak regulation for startup and shutdown of gas-fired generation unit, etc. (3) Strengthen environmental impact assessment. Strengthen the coordinated development between renewable energy utilization projects (by recycling emission pollutants from power generation by waste incineration in JJJ and surrounding areas), surrounding natural environment and overall land layout; enhance the environmental protection awareness of renewable energy manufacturing enterprises, improve production process, promote application of environmental protection technology, and reduce the impact of renewable energy production and conversion on the ecological environment and life and production of citizens, to ensure clean production of renewable energy sources. Relevant environmental protection management system for renewable energy projects shall be further improved, to specify environmental protection requirements, strengthen environmental review and give full play to environmental protection binding force in the approval process.

Implementation of planning

According to the renewable energy development prospect in JJJ, the priority task plan for the renewable energy development in this region will be carried out year by year in stages as follows:

Figure 22-11 Implementation of planning



Key Task	2016	2020	2025	2030
Realize green and low-carbon development in Olympic Games Area	(1) Achieve a high proportion of renewable energy-based power supply			
	(2) Promote diversified application of renewable energy sources			
	(3) Accelerate integration of green transportation, distributed energy resource and intelligent energy			
	(4) Implement system and mechanism innovation to make the market player play an effective role			
Achieve a high proportion of renewable energy-based development in Xiong'an New Area	(1) Adhere to the principle of green development			
	(2) Make medium and long term overall planning for various energy sources			
	(3) Improve innovative development of a high proportion of renewable energy sources in the region			
Realize coordinated development of renewable energy sources in JJJ	(1) Being green and low-carbon oriented, promoting energy consumption and supply revolution			
	(2) Strengthen overall planning for the renewable energy development in JJJ			
	(3) Improve policy mechanism for the coordinated development of renewable energy in JJJ			
Realize coordinated development of renewable energy sources in JJJ and surrounding areas	(1) Promote energy Integration construction			
	(2) Strengthen power exchange between provinces and cities			
	(3) Strengthen environmental impact assessment			

Key Measures

Strengthen top-level design for renewable energy development in JJJ

Total energy consumed in JJJ accounts for over 10% of that all over the country, with the energy structure mainly on coal, clean energy taking a low proportion, with high external dependence and confronted with great pressure in energy conservation and emission reduction, therefore, increasing the proportion of renewable energy, reducing the utilization of coal, accelerating the development of renewable energy like wind power, photovoltaic power and geothermal power, etc., and optimizing energy structure have become important contents for the coordinated development in JJJ and supply-side structural reform of the energy field. Top-level design for renewable energy development in JJJ shall be strengthened to promote energy transformation in JJJ. Contents includes: (1) come up with *Medium and Long-term Development Plan for Renewable Energy Sources in JJJ* as soon as possible under the guidance of *Outline of the Coordinated Development Plan for JJJ* deliberated and approved by the Central Government in April 2015, to specify the goal, key tasks and implement approach for the renewable energy sources development in JJJ; accelerate energy production and consumption revolution process, to take the lead in realizing energy replacement system by taking the clean energy, low-carbon and renewable energy sources as the core and energy system mainly on fossil fuel, to lay a good foundation for the ecological environmental protection and industry transformation and upgrading in JJJ. (2) Consolidate and integrate goals, routes and measures put forward in the *Energy Development Planning*, in particular the *Renewable Energy Development Planning* released in Beijing, Tianjin and Hebei regions, and interface with the *Outline of the Coordinated Development Plan forJJJ*, to reflect the functional orientation of "urban agglomeration by taking the capital as the core, regional overall coordinated development reform area, national innovative new engine driving economic growth and environmental improvement demonstration zone for ecological rehabilitation" in JJJ concretely. (3) In the development planning released in JJJ in the future which is related to energy, the realization of concept of rapid development of renewable energy sources shall be taken as important content of the planning and reflected practically. (4) A roadmap for the renewable energy development shall be issued as soon as possible, break the general objective into specific objectives at development stages in Beijing, Tianjin and Hebei regions according to the direction, key points, goals and tasks determined in the *Medium and Long-term Development Plan for Renewable Energy Sources in JJJ*, to specify basic conditions, main obstacles, key areas and key emphasis in work for the realization of renewable energy sources development at different development stages. Action plans on the aspect of technical research and development, market cultivation, investment orientation, system and mechanism innovation and talent training shall be proposed according to major bottlenecks, technical potential and important tasks confronted in priority areas and key technology fields.

Improve cooperativeness of JJJ in promoting renewable energy development

Coordination mechanism to promote fast renewable energy development in JJJ shall be established to promote renewable energy sources development in the region, with the purpose of making breakthroughs in four difficult tasks: planning, approval, financing and coordination. Priority shall be given to breaking administrative barriers in these three places, and to accelerating the pioneered breakthrough in energy production and consumption revolution in JJJ with system and mechanism innovation. Specific contents include: (1) set up the idea of "a board of chess" to determine the functional orientation of these three provinces and cities in promoting the renewable energy development, enhance integrity and specify the roles and responsibilities of these three provinces and cities in promoting energy production and consumption revolution based on their respective characteristics and comparative advantages. (2) Remove local protectionism and strengthen joint legislation and collaborative law enforcement, to conduct the strictest standardized and unified supervision on energy production, circulation, consumption and pollutant discharge. Make overall arrangement and formulate regional energy policy, reduce the proportion of high energy consumption industry, and give full play to superiority of the Beijing Science and Technology Innovation Center and Tianjin Advanced Research and Development Base, to drive Hebei Province to vigorously increase renewable energy sources equipment manufacturing share. (3) Optimize the energy supply structure in JJJ, intensify clean energy transmission outside the region and accelerate construction of energy infrastructures like the extra-high pressure and large capacity power transmission channel and natural gas supply pipeline. Increase the supply scale of clean energy in the region and give priority to support the development, consumption and output such clean energies as wind power, photoelectric power and geothermal energy. Make overall arrangement for regional power and heating power demand, make rational layout for construction of new energy base and increase proportion of clean energy in the whole region. (4) Strictly control total coal consumed in the whole region, vigorously promote electric power replacement, conduct governance of scattered coal in rural areas, improve coal quality standard, standardize coal supply, intensify regulation of all links and cut off circulation channel of low-quality bituminous coal, so as to provide greater market space for renewable energy development and digest excess capacity from new energy power in the surrounding areas. (5) Pay attention to rural integrated energy service system in the development zone, promote clean energy replacement, accelerate rural power grid upgrading and construction of natural gas pipelines, and develop methane and complementary and distributed energy of wind power and light energy by adjusting measures to local conditions.

Strengthen policy support for the renewable energy development in JJJ

To accelerate the renewable energy development in JJJ and accelerate the energy production and consumption revolution process in the region, powerful policy measures must be taken, concrete contents of which include: (1) set up "energy transformation fund in JJJ" to control coal production and consumption, conduct transformation and upgrading of traditional energy industry, cut overcapacity in a scientific and orderly way, improve energy consumption level of low-income groups, especially to provide low-interest financing for the research and development of renewable energy sources, equipment manufacturing and construction of public test platform, etc. (2) Find a breakthrough by means of system and mechanism innovation, break barriers that restrict coordinated development and achieve coordination in terms of systems and mechanisms, so as to carve out a way for the renewable energy industry development in JJJ and provide system guarantee. (3) As for the renewable energy development in key areas like Zhangjiakou City and Xiong'an New Area, special policy shall be given by following the principle of handling special cases with special method and going and trying beforehand, to increase the application scope and proportion of renewable energy on a large scale, and take the lead in realizing the development goal of a high proportion of renewable energy, to make the whole region play a demonstrative and leading role in the energy transformation process.

Innovate market system and mechanism for the renewable energy development in JJJ

Although JJJ is a developed region, its renewable energy development is similar to that of the whole country, with restrictions in system and mechanism, for example, market-oriented reform in energy field is far from completed; price-forming mechanism for the oil gas, electric power and heating supply is not yet perfect; grid enterprises still have public power in the aspects of grid connection, transaction and dispatching; governments of all levels control project approval, electricity price and power distribution right; trans-provincial and trans-regional electricity transaction are still dominated by administrative bodies. As function orientation and management system reform of state-owned enterprises are not in place; profitability of grid enterprises infringes public welfare; monopoly restricts openness; government lacks supervision; openness of power market is very limited; access of non-public capital in the energy market is strictly restricted, which prevent the market mechanism playing an effective role; bottleneck of the clean power development begins to emerge. Under the background of coordinated development of JJJ, this region shall take the lead in innovating the renewable energy system and mechanism and breaking industrial monopoly to form fair competition pattern. Specific contents: (1) break administrative monopoly to form competitive energy market. As for oil gas industry, administrative monopoly attached on natural monopoly shall be broken up, to gradually form market structure with oligopoly competition and relative perfect competition coexisting through business splitting and introduction of private capital. The power industry further makes power transmission and dispatching function non-profit on the basis of plant-grid separation through system reform of separating transmission from distribution and independent dispatching, marketizes distribution and sale link and forms competition mechanism at the power generation side and power utilization side. (2) Reform and innovate energy price forming mechanism. Establish and perfect the mechanism of determining price for fossil fuel resources like the coal, petroleum and natural gas mainly according to the market supply and demand relationship, to improve flexibility of price adjustment. Accelerate electricity price reform and lift price control in competitive sector on the power generation side and consumer side, to form linkage mechanism of on-grid price and retail electricity price, so as to make the electricity price reflect change in cost and supply and demand relationship at different periods of time and different regions in a more real way. (3) Promote trans-regional transaction of electricity in an orderly manner. With acceleration of energy transformation in JJJ, electric power will gradually become the leading type of terminal energy consumption. As the scale of trans-regional transaction of electricity increases greatly, forming of perfect national and regional power market shall be promoted by taking the establishment of trans-provincial and trans-regional transaction platform as the sally port and lifting prices control as the premise, to vigorously promote trans-regional market transaction of electricity. Market players like power generation players and consumers in different areas can enter the platform to conduct autonomous transaction through bidding. With the opening up of the market at the sale side, independent power sale enterprises are introduced and incorporated into the power transaction platform. Relevant reform is carried out to perfect the power grid dispatching mode and power grid wheeling charge pricing mechanism, to ensure unblocked power transmission. (4) Carbon emission transaction market is established gradually. Regional and national carbon emission transaction market are gradually formed on pilot basis by referring to EU's experience in establishing carbon emission transaction market and according to China's practice from controlling energy consumption intensity to further control total energy consumed reasonably.

Strengthen publicity to deepen understanding of the general public in JJJ on accelerating renewable energy development

Deepening understanding of the general public on the role of the renewable energy in optimizing the energy structure in JJJ and improving ecological environment in the local area is an important task to accelerate energy production and consumption revolution in JJJ, and includes the following two aspects: (1) carry out renewable energy propaganda and promotion activities extensively. Specifically, the local government shall carry out special promotion activities through the television station, press, magazine and internet, etc., and release publications, research reports and important activity information, etc. by using such resources as relevant government portal website; competent education authorities shall incorporate the knowledge of renewable energy into primary and middle school textbooks, to make teenagers understand renewable energy from childhood and establish the awareness of developing and utilizing renewable energy; actively encourage the general public to participate in relevant activities about renewable energy, including participating in preparation of relevant planning and discussion and decision-making of development of renewable energy projects. (2) Make general public in JJJ actively participate in renewable energy production and consumption, construct the renewable energy project jointly and share renewable energy development achievements. Specifically, encourage urban residents in JJJ to make use of the roof to develop solar energy projects mainly on self-generation for self-use; adopt agriculture-solar complementary power generation and hydro-solar complementary power generation mode; encourage rural residents to actively develop and utilize renewable energy; encourage the general public to purchase new energy automobiles actively, and to reduce usage amount of oil-fuelled automobiles; encourage the general public to directly participate in various renewable energy investments and purchase green energy certificates voluntarily, and so on.

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[i] Zhu, X., Bai, Q., & Zhang, X. (Eds.) (2017). *Good Practice and Success Stories on Energy Efficiency in China*. Copenhagen: Copenhagen Centre on Energy Efficiency, UNEP DTU Partnership.

[ii] Xinhua. (2017, 06 03). *More Chinese work in tertiary sector: report*. Retrieved 06 26, 2017 from XinhuaNet: http://news.xinhuanet.com/english/2017-06/03/c_136337673.htm

[iii] UNEP. (2016). *Green is Gold: The Strategy and Actions of China's Ecological Civilisation.* UNEP.

[iv] State Council. (2015, 09 22). *Full Text: Integrated Reform Plan for Promoting Ecological Progress*. Retrieved 06 26, 2017 from The State Council: http://english.gov.cn/policies/latest_releases/2015/09/22/content_281475195492066.htm

[v] NBS. (2017, 02 28). *Statistical Communiqué of the People's Republic of China on the 2016 National Economic and Social Development*. Retrieved 06 27, 2017 from National Bureau of Statistics of China: http://www.stats.gov.cn/english/PressRelease/201702/t20170228_1467503.html

vi Retrieved from http://www.ndrc.gov.cn/zcfb/zcfbghwb/201612/P020161222570036010274.pdf

[vii] Retrieved fromhttps://ens.dk/sites/ens.dk/files/Globalcooperation/flexibility_in_the_power_system_v23-lri.pdf

viii https://www.unendlich-viel-energie.de/media/file/249.AEE_Potenzialatlas_Bioenergie_Sachsen_jan13.pdf
https://www.unendlich-viel-energie.de/media/file/971.EWAtlas2017_Mai17_web.pdf

[ix] Retrieved from http://reneweconomy.com.au/how-wind-and-solar-broke-the-worlds-electricity-markets-84505/

[x] Prognos AG. Flexibility of thermal power plants - Focus on the flexible operation of existing coal-fired power plants, internal unpublished report on behalf of Agora Energiewende

[xi] Michels, A., 2016. Trockenbraunkohle erhöht die Flexibilität, Bonn: BINE Informationsdienst – FIZ Karlsruhe

Heinzel, T., Meiser, A., Stamatelopoulos, G.-N. & Buck, P., 2012. Einführung Eimühlenbetrieb in den Kraftwerken Bexbach und Heilbronn Block 7. VGB PowerTech, November, pp. 79 – 84

Agora Energiewende (2017): Flexibility in thermal power plants – With a focus on existing coal-fired power plants

[xii] Retreived from https://ens.dk/sites/ens.dk/files/Globalcooperation/flexibility_in_the_power_system_v23-lri.pdf

[xiii] Retreived from http://www.nrel.gov/docs/fy14osti/62125.pdf and "Flexible Coal Evolution from Baseload to Peaking Plant", NREL

[xiv] "Current and Prospective Costs of Electricity Generation until 2050", Deutsches Institut für Wirtschaftsforschung
http://www.diw.de/documents/publikationen/73/diw_01.c.424566.de/diw_datadoc_2013-068.pdf
"Flexibility options in electricity systems", Ecofysis
http://www.ecofys.com/files/files/ecofys-eci-2014-flexibility-options-in-electricity-systems.pdf

[xv] "Current and Prospective Costs of Electricity Generation until 2050", Deutsches Institut für Wirtschaftsforschung
http://www.diw.de/documents/publikationen/73/diw_01.c.424566.de/diw_datadoc_2013-068.pdf
" Flexibility in thermal power plants", Agora Energiewende
https://www.agora-

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energiewende.de/fileadmin/Projekte/2017/Flexibility_in_thermal_plants/115_flexibility-report-WEB.pdf
www.eecpowerindia.com/codelibrary/ckeditor/ckfinder/userfiles/files/VGB%20Th%20Flexibility%20REV3_Part%201.pdf

[xvi] Kraft, A., 2015. Virtuelle Kraftwerke und Wärmespeicher. s.l.:s.n.

[xvii] Prognos, 2017. Berlin, internal and unpublished report by Frank Peter et al., Agora Energiewende.

[xviii] Retreived from https://transparency.entsoe.eu/generation/r2/actualGenerationPerGenerationUnit/show

[xix] Retreived fromhttp://globalenergyobservatory.org/form.php?pid=44325 and https://en.wikipedia.org/wiki/Bexbach_Power_Station

[xx] COWI. ‘Cost estimate input to EDO on power plant flexibility’, internal unpublished report on behalf of Danish Energy Agency

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