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CNREC
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CHINA NATIONAL RENEWABLE ENERGY CENTRE

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China Renewable Energy Outlook

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Energy Research Institute of Academy of Macroeconomic Research/NDRC

China National Renewable Energy Centre

Executive Summary

Implementing Unit

Financial Support

Technical Support

Domestic Supporting Institutes

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

“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 detailed results of our research are presented in the full Outlook report. In the present booklet, we present the main findings and key results to give the reader a quick overview. For the more detailed assumptions, analyses and results we strongly recommend reading the full report.

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

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.

Stated Policies Scenario

Implementation of currently 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"

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.

Below 2 °C Scenario

Implementation of the Paris Agreement target to reduce the impact of the greenhouse gas emissions to a temperature increase below 2 °C

Coal Reduction and a High RE Share in 2050 at 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.

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.

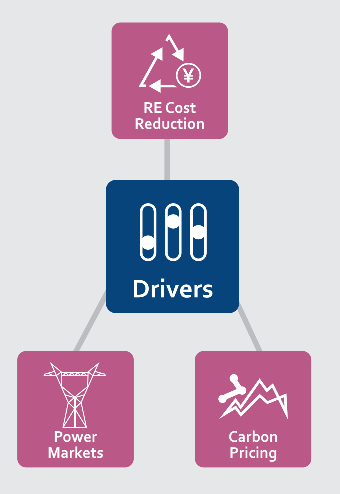


Figure 1
The main drivers for the energy transformation on the supply side are RE cost reduction, efficient power markets and carbon pricing, all incentives for CO_2 reduction.
On the demand side strong energy efficiency measures are needed

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.

Table 1: 2020 Targets And Scenario Achievements			
	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%

Table 1
Key targets for RE technologies in 2020 in the 13th five-year plan (FYP), compared to the achieved deployment in the two main scenarios.

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.

Requirements for Flexible Dispatch of Coal Power Plantsand 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.

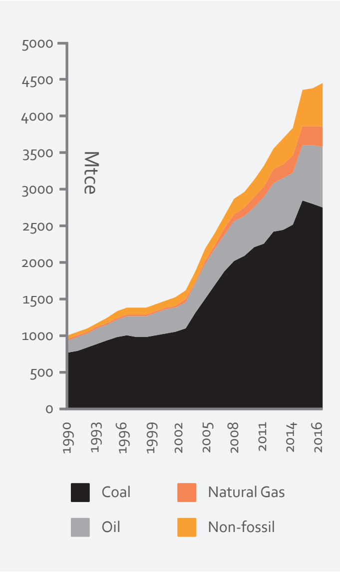
This development comes with a price. Economic growth has been enabled through enormous growth in energy consumption. From 1978 to 2016, China's total energy consumption soared from 570 Mtce to 4,360 Mtce; the share of fossil fuel in the energy mix has been more than 85%, and coal's share higher than 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.

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



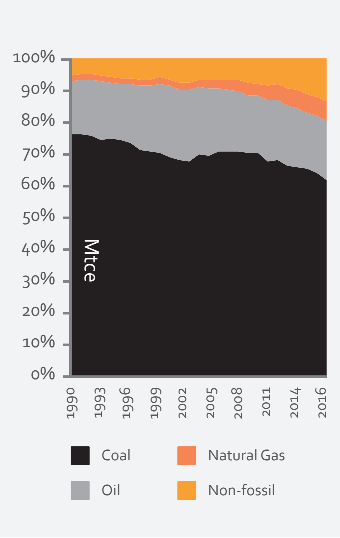


Figure 2
Development of primary energy demand in China from 1990 to 2016 by fuel type, in absolute value (Mtce) and in percent of the total consumption each year. Only recently the growth trend and the high coal share have decreased.

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.

Ratification Of The Paris Agreement

China ratified the Agreement September 2016.

On 5 October 2016, the threshold for entry into force of the Paris Agreement was achieved.

Per 1 October 2017, 166 of 197 Parties to the Convention have ratified the Agreement.

Today's Energy System and 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.

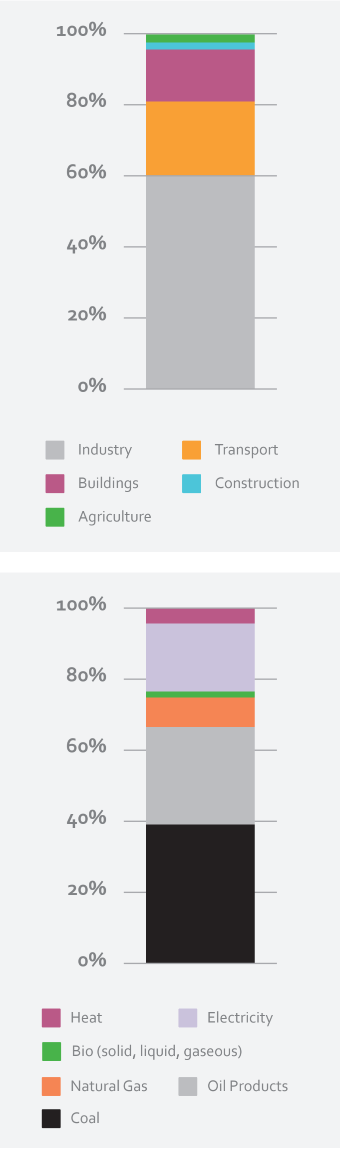


Figure 3
The final energy demand in 2016 by sector, and by primary and secondary fuels in percent of the total final energy demand. Industry is the most energy-consuming sector, and coal and oil are the dominant fuels, followed by electricity.

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.

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.

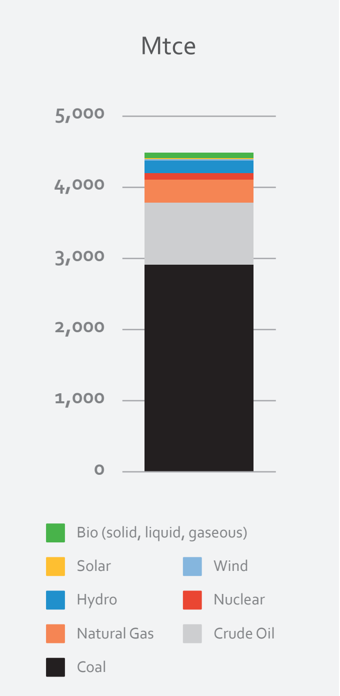
Need for RE Subsidy Reform

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

Figure 4

Primary energy demand in 2016 by fuel type. Coal covered 65% of the total demand and non-fossil fuels 13%, calculated by the coal substitution method for non-fossil fuels.



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.

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).

* Note: Doe 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.

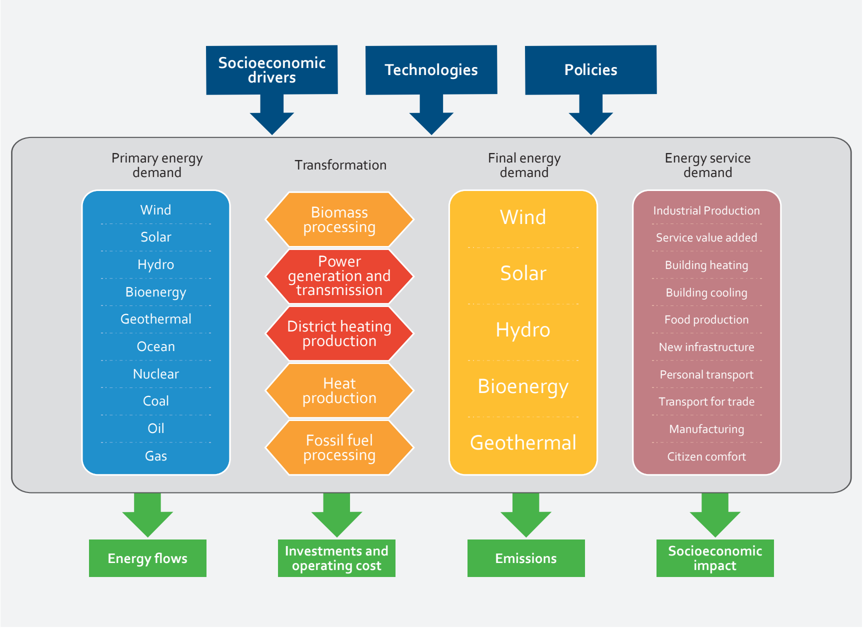


Figure 5
The energy system modelled by CNREC modelling tools. The power and district heating system is modelled by a bottom-up energy dispatch model on a provincial level with hourly time steps and with power transmission constraints. The end-use sectors and transformation outside of the power sector is modelled by a sector-specific bottom-up model on national level. The socioeconomic impact is modelled by a computable general equilibrium model.

Theoretical Foundation and Meaning of the *Three-Line Development Concept*

The Outline of the 13th Five-Year Plan for Economic and Social Development of the People's Republic of China points out the future development direction and overall strategy of China. From the perspective of vertical axis of time, we should persist in the Four Comprehensives, i.e. comprehensively completing the building of a moderately prosperous society, comprehensively deepening reform, comprehensively implementing the rule of law and comprehensively enforcing strict party discipline, insist on having development as the top priority, and laying a solid foundation for realizing the second goal of Two Centenary Goals while realizing the first goal of Two Centenary Goals; from the perspective of horizontal economic and social axis, we should firmly establish and implement the Five Development Ideas, i.e. innovation, coordination, green, opening-up and sharing, to promote the overall layout of Five in One, that is: economic construction, political construction, cultural construction, social construction and ecological civilization construction.

China is on a new development path, on which ecological civilization construction has become core content, that is: "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 been become an important concept for economic and social development in the 13th Five- Year Plan period and even in the longer term. Green development, as an important part of new development ideas, 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 hot topic 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", which is exactly the most appropriate manifestation of "green" development idea.

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 is endowed with a high-carbon energy structure, with the total energy consumption still ranking the first in the world. Supported by such structure, China's economic construction would definitely result in high emission 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 energy sustainable 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 livable standard specified by WHO. 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.

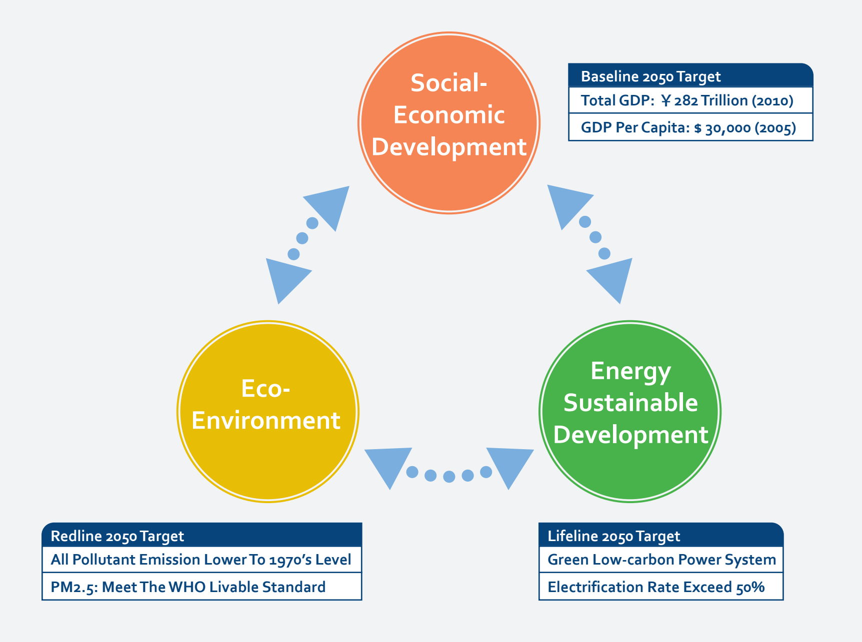


Figure 6
The "Three-line development" concept

The baseline – **the socioeconomic development targets** – must be reached – **282 Trillion RMB** in 2050.

The red line – **the ecological boundaries** – cannot be overstepped.

The lifeline – **the sustainable energy development** – is the instrument to reach the baseline without overstepping the red line.

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.

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
Below 2 °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: Main Assumptions

Population and Economy

GDP 282 Trillion RMB in 2050

Population 1.38 Billion in 2050

Energy Demand

Ambitious EE Targets

2050 final energy consumption less than 3,500 Mtce in both scenarios

Electrification (Minimum)

	Stated Policies	Below 2 °C
2020	20 %	20 %
2030	25 %	30 %
2050	40 %	55 %

Electric Vehicles

At least 400 million vehicles in 2050

Energy Supply

Non-fossil Fuel Share (Minimum)

	Stated Policies	Below 2 °C
2020	15 %	20 %
2030	20 %	40 %
2050	60 %	75 %

Environment

2050 CO_2 emission less than 3 Gt in Below 2 °C Scenario

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

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 6: 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 5: Resulting RE share of power generation in the two scenarios

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%

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.

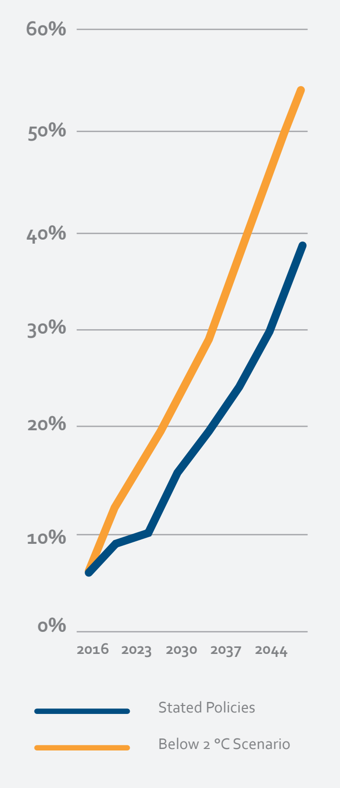
Renewable Energy Becomes Central

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 8
RE share of primary energy demand in percent, calculated by the coal substitution method



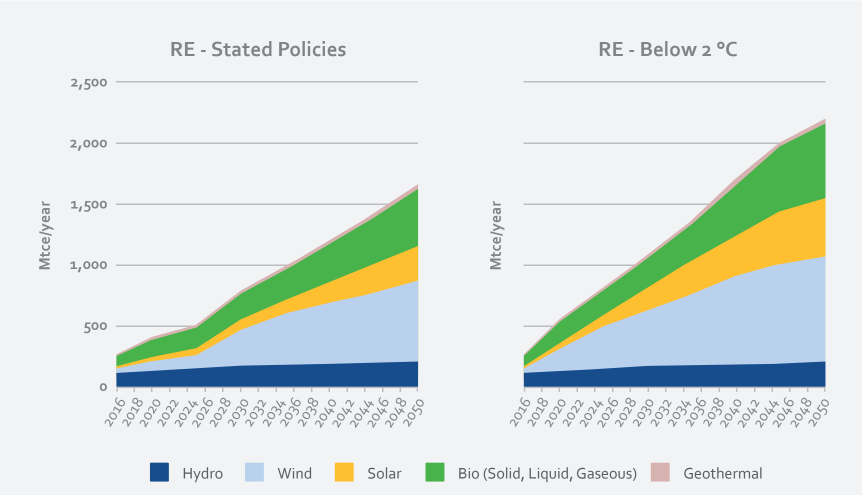


Figure 7
Energy production (Mtce) from renewable energy sources in the two main scenarios (2016-2050)

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.

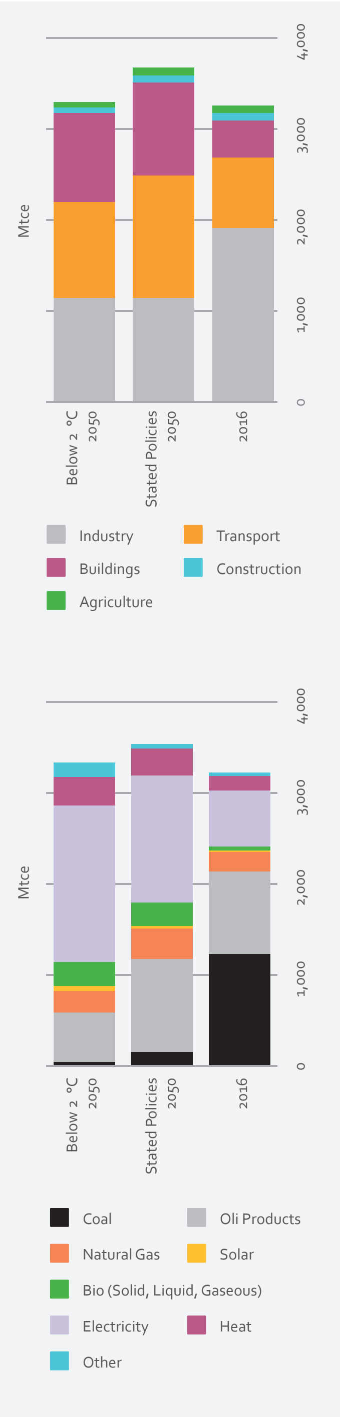
The development of energy demand is characterised by a high degree of electrification and a shift to less energy-intensive industry. A collection of extensive energy efficiency measures is in place in both scenarios. This is the main reason the energy demand follows a similar trend in the two scenarios 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 10
Final energy demand (Mtce) in 2050 in the two scenarios compared with today, by sector and fuel type



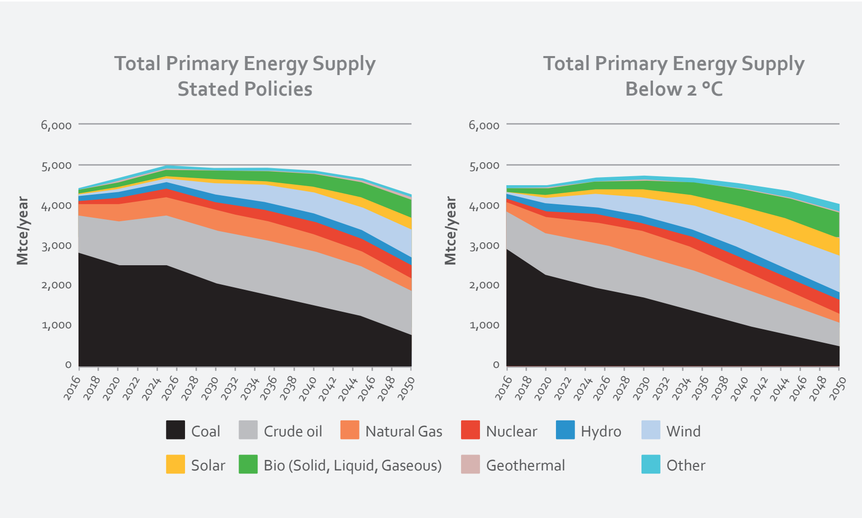


Figure 9
Development of the primary energy demand in the two scenarios (Mtce) 2016-2050, by fuel type

Environment – CO_2 Emission

Achieving Absolute Emission and Per Capita Emission Targets

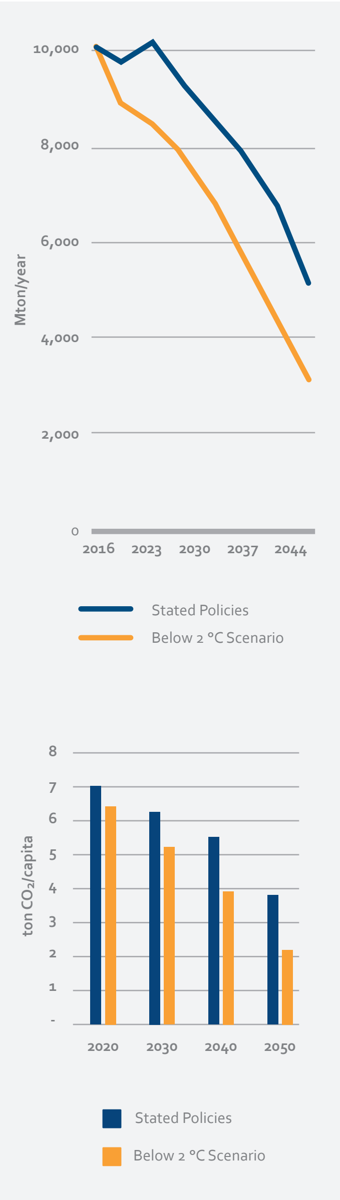
Cuts in fossil fuel consumption will successfully set the energy sector on a decarbonisation path. Swift short-term actions lead to initial CO_2 reductions, especially in the Below 2 °C Scenario where emissions from the energy sector have already peaked.

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



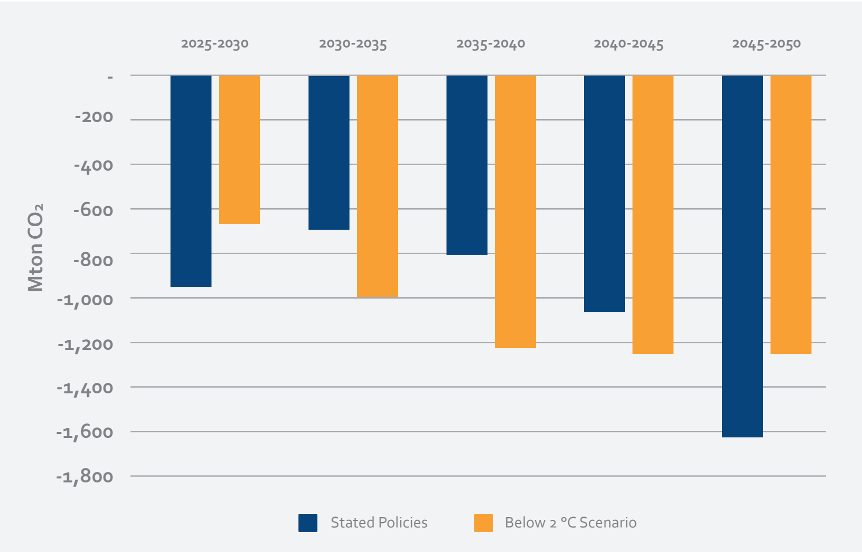


Figure 11
CO_2 reduction (Mton) in five-year periods from 2025 to 2050 in the two scenarios

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.

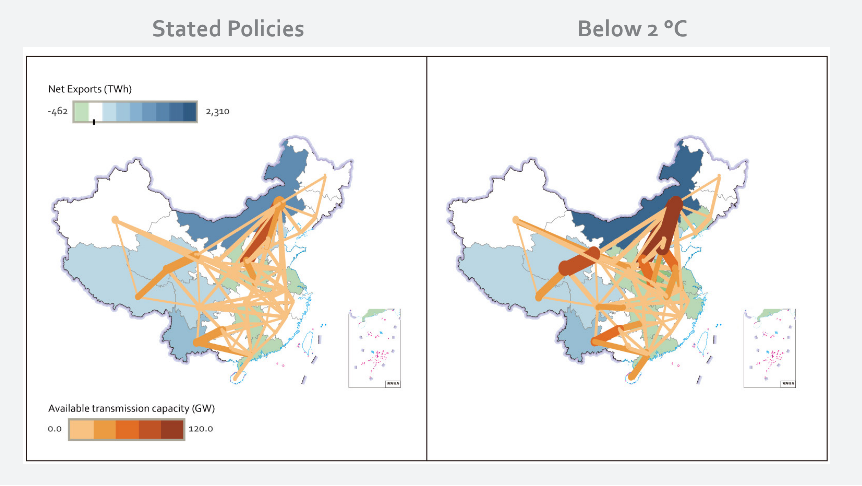


Figure 13
The transmission system and the power flow (net export/net import) between the provinces in 2050 for the two scenarios

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.

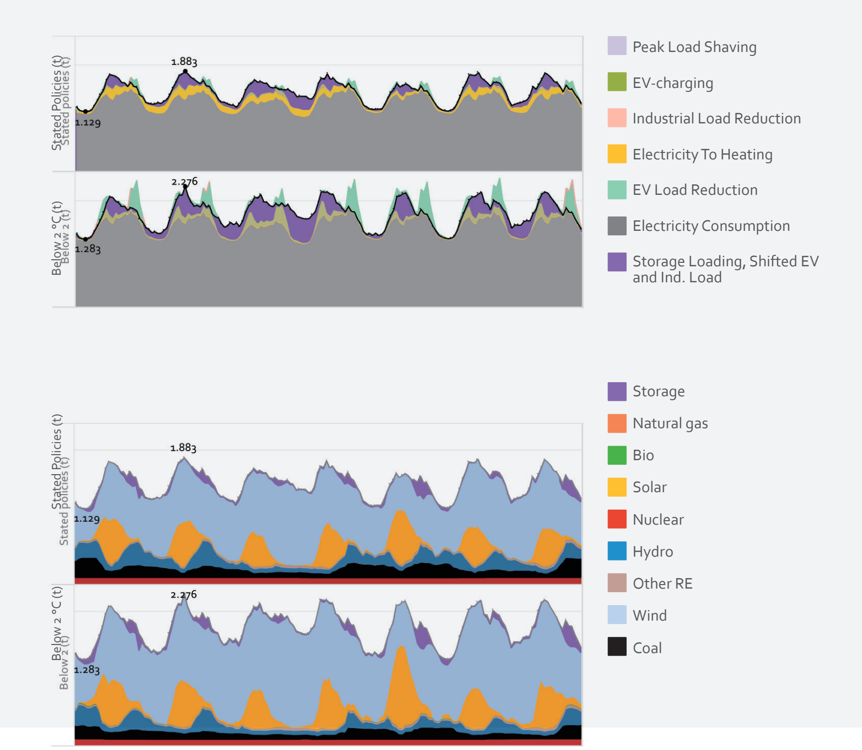


Figure 14
Hourly demand-side response and supply dispatch of the Chinese power system for one week in 2050 for the two scenarios

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

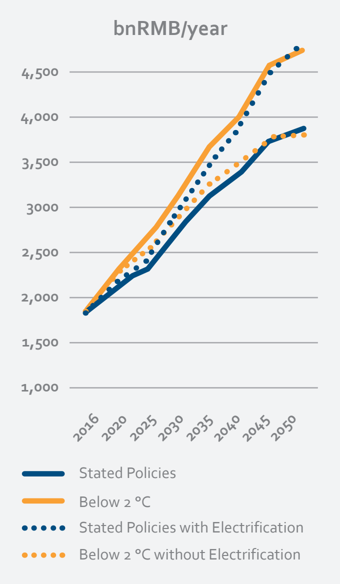
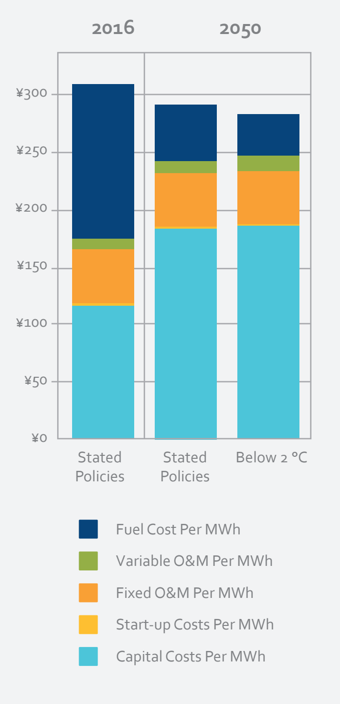


Figure 16
Power system costs (RMB/MWh) for the two scenarios in 2050 compared to today's cost structure and level



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

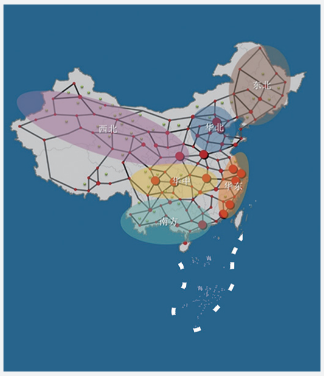
China's future power grid development should focus on supporting the national economic development and the overall strategy for energy transformation. The future grid will activate advanced technology and adapt to a market-oriented operating mechanism. The development should support the coordination 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.

Figure 17
The power transmission system in 2050 (principal layout)



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.

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