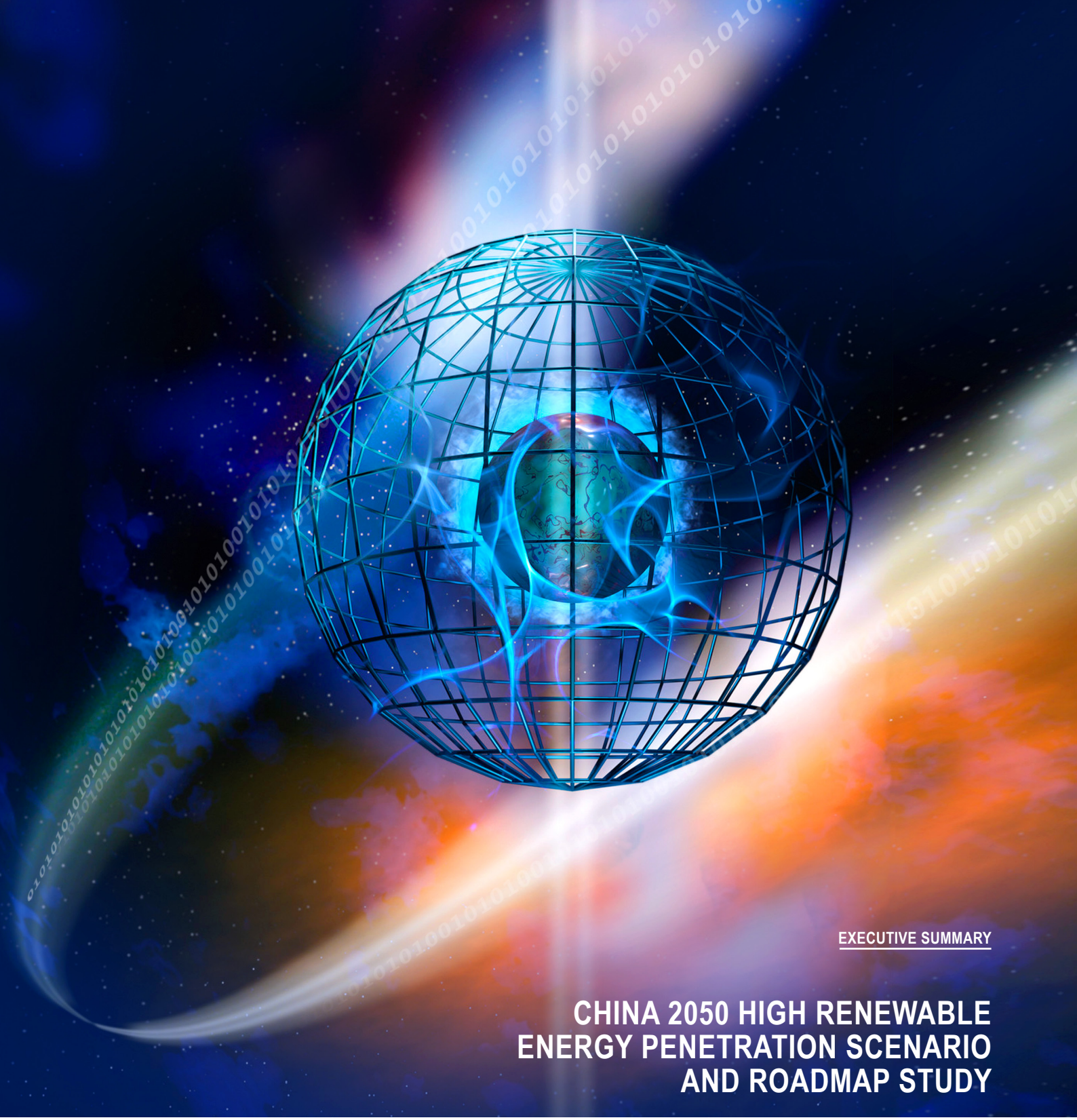

EXECUTIVE SUMMARY

CHINA 2050 HIGH RENEWABLE ENERGY PENETRATION SCENARIO AND ROADMAP STUDY

ENERGY FOUNDATION
能源基金会

ENERGY RESEARCH INSTITUTE
NATIONAL DEVELOPMENT AND REFORM COMMISSION

Energy Research Institute
National Development and Reform Commission

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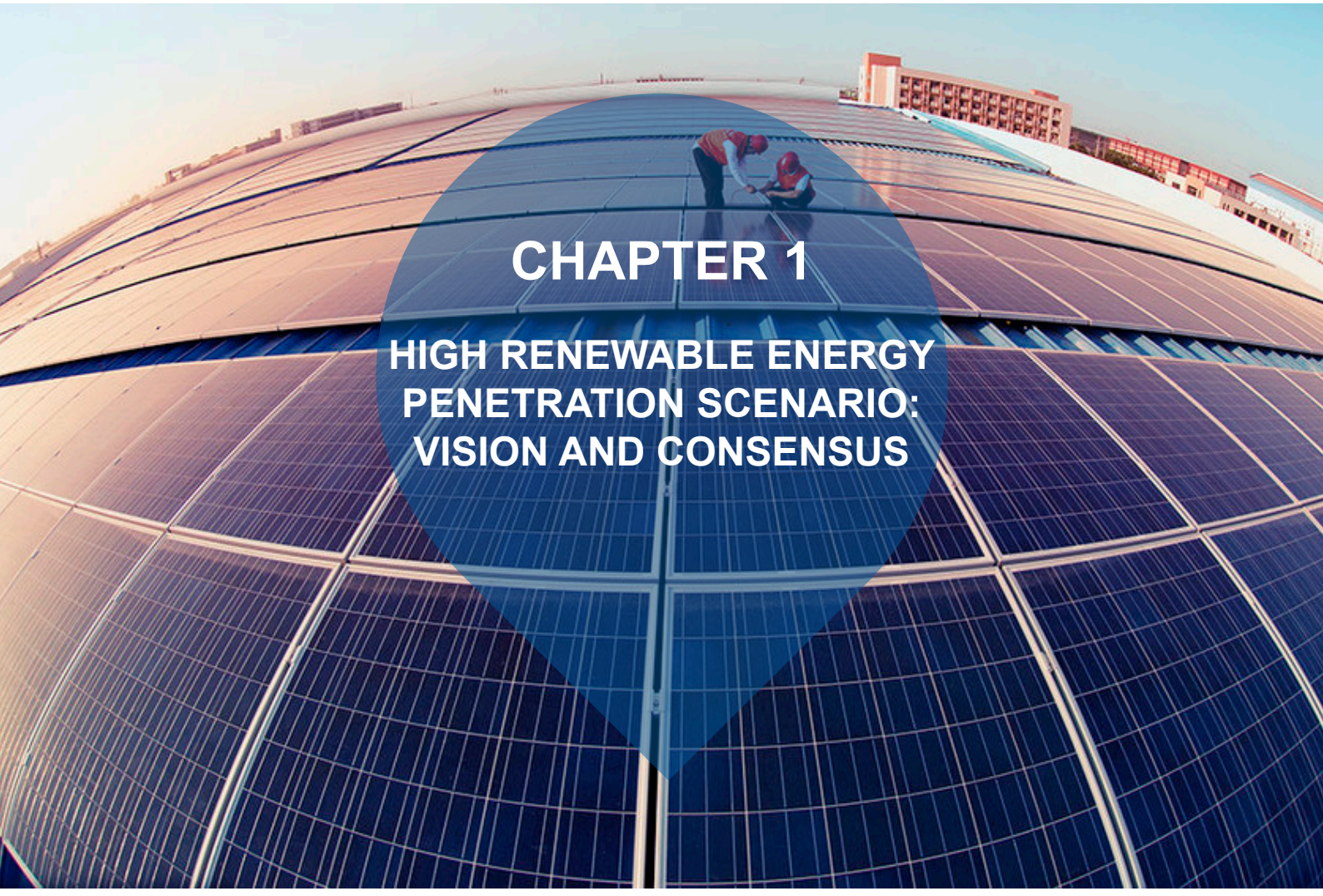
Do not ever think about that we can escape, our every each step determine the final outcome, our foot steps are moving towards the end of own chosen target.

— Milan Kundera



CHAPTER 1

HIGH RENEWABLE ENERGY PENETRATION SCENARIO: VISION AND CONSENSUS

We are continuously writing new chapters in our history. In the history of energy, it is an irreversible path that we will gradually move away from dependence on fossil fuels and transit to a “high renewable energy penetration” future. The "China 2050 High Renewable Energy Penetration Scenario and Roadmap Study" analyzes how China can gradually phase out fossil energy, especially coal, from its leading role in China's energy development, and give low-carbon green electricity a prime part to play.

1

CONSENSUS ON DEVELOPMENT

Strengthen Environmental Constraints

Given the severe landscape of tightening resource constraints, serious environmental pollution, and degraded ecological systems, it is necessary to establish a strategic turning point in energy development through the imposition of environmental constraints. China needs to project an ecological civilization concept of respecting, complying with and protecting the nature. China must also put ecological civilization development high on its agenda, and integrate it into all aspects and processes of economic, political, cultural, and social development. The goal is to build a beautiful China and realize sustainable development. To achieve this grand objective, China needs to significantly cut back on pollution emissions and restore to levels of the 1970s and 1980s. Based on the environmental constraints, a backcasting mechanism is formed to reduce coal and oil consumption. The study also sets restrictions on greenhouse gas (GHG) emissions - as 3.5 billion tons for the whole energy sector and 1.5 billion tons for the power sector in 2050.

Optimize Development Paths

On the basis of broadly seeking expert advice, as well as learning and summarizing the contents and methodologies of advanced international researches, this study establishes a decision-making framework concerning the development goal of high renewable energy penetration in China. The decision-making process is carried out by integrating techno-economic appraisal, energy system optimization, socio-economic assessment, and externality analysis.

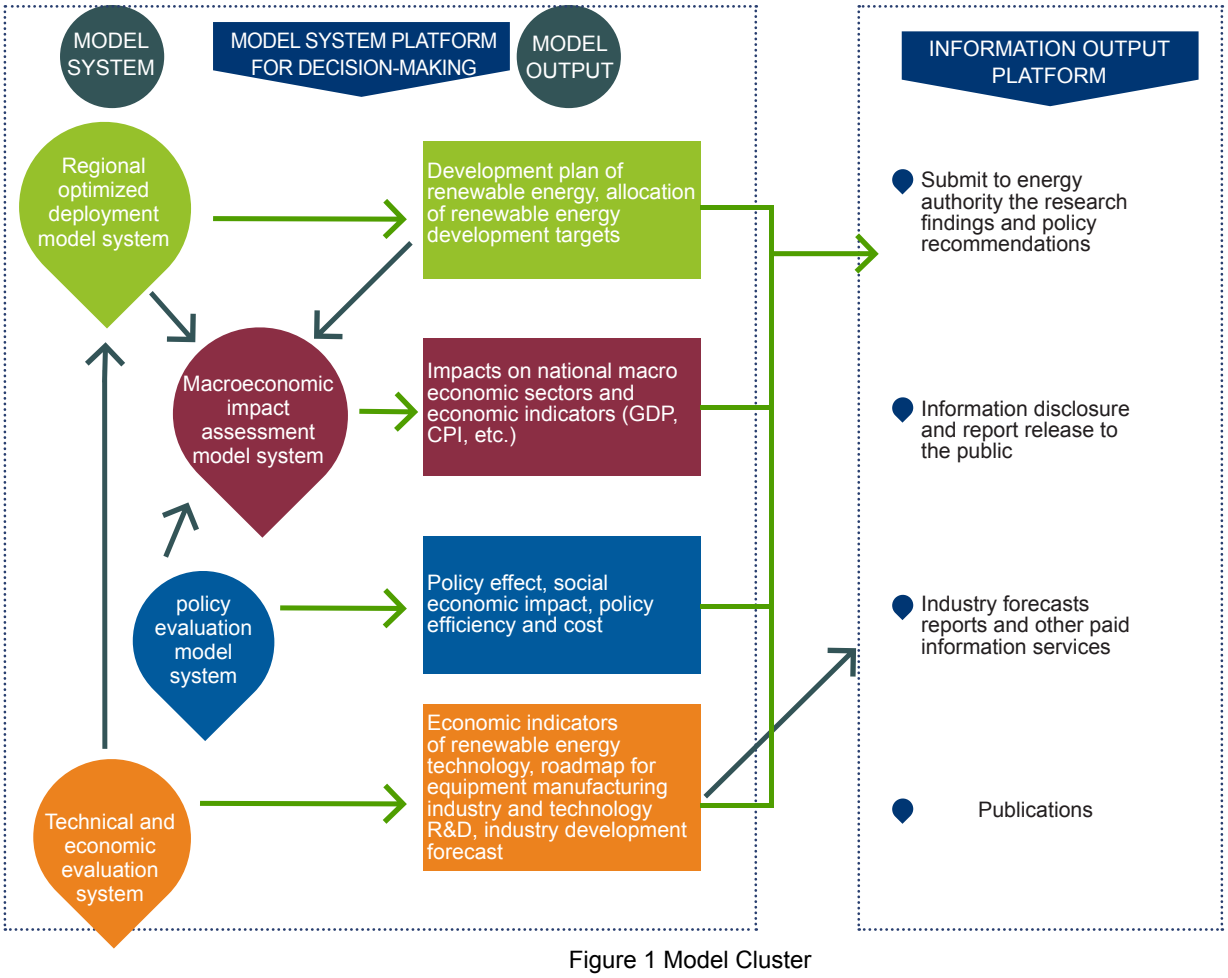


Figure 1 Model Cluster

This study is based on scenario modeling aimed at the development and integration of high levels of renewable energy. It sets up China's 2050 electricity consumption demands, energy resource constraints, GHG emission constraints, atmospheric pollution and other environment capacity constraints, techno-economic features of electricity technology and other scenario information. This study adopts a host of assumed conditions, including the upgrading of power technologies, the operational constraints of power systems, energy and resource prices, and power demand. By employing a power system optimization model as the research tool and taking 2010 as the baseline year, this study analyzes the optimal operation of power system and system expansion plan that meets various constraints under the reference and high penetration scenarios in 2050. It analyzes the energy substitution as well as environmental, economic, and social benefits, and calculated the direct and indirect cost of developing renewable energy. Based on such information, this study optimizes the development paths for the power system between 2015 and 2050 under different scenarios, from the perspectives of geographical distribution, distribution of time and the operation of the power system. The output of this study also includes the corresponding

implementation schemes for different development paths and the outlook of power system technologies and operation management.

Adopt Target-Oriented Approach

China needs to press ahead with significant reforms in energy production and consumption patterns to fully realize its goal of a clean, low-carbon, secure and reliable energy system by 2050. China must take into account the lock-in effect of traditional energy systems, plan the future energy system in advance and establish new energy production and consumption model. This will require China to constantly and significantly reduce the proportion of fossil energy, increase the proportion of renewable energy in energy consumption, and develop scientific geographical distribution, industrial structure, as well as production and living patterns that well supports energy efficiency and renewable energy development.

Fossil energy for end-use and energy conversion processes will be significantly reduced, totaling no more than 1 billion tons by 2050. Renewable energy will be vigorously developed, accounting for over 60% of the energy consumption and over 85% of the electricity consumption.

2 LONG-TERM VISION

Social Economy - Reach the Level of Medium-Developed Countries

China's per capita gross national product (GNP) will reach the level of medium-developed countries by the middle of the century. At that time, China will realize modernization, restore a clean environment, and become a prosperous, democratic and civilized socialist country. This is a scientific consensus reached in the whole Chinese society.

By 2050, China's population will be 1.38 billion and GDP will reach RMB282 trillion (constant 2010 RMB), which is 7 times of China's GDP in 2010. By then, per capita GDP will reach US$30,000 (constant 2005 US dollar, US$50,000-60,000 per capita) and China's GDP will account for one-third of the world's total. By comparison, in 2011, OECD had a population of 1.241 billion and its GDP accounted for 73% of the world's total, while China had a population of 1.341 billion and its GDP only accounted for 10% of the world's total. By 2050, China will be the largest economy in the world.

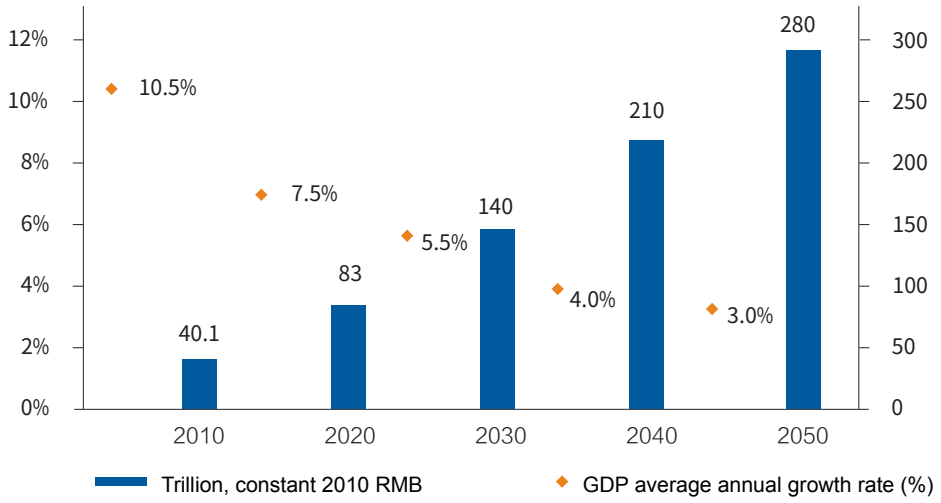


Figure 2 2010-2050 GDP Growth Rate

Ecological Environment - Bring Back Clear Water and Blue Skies for "Beautiful China"

The development target of a "beautiful China" is a strategic target with abundant meanings, and the key is to realize harmony between man and nature, between people, and between man and society. For that matter, we need to first build a beautiful homeland featuring intensive and efficient production, comfortable living, healthy ecosystem, clear water and blue skies. The action plan to achieve a beautiful China is mainly manifested in the following three aspects:

First, the level of intensive and economical utilization of resources is significantly increased. Going forward, China will need to further advance resource use efficiency, promote the transformation of resource utilization patterns, enhance full-process conservation management, vigorously develop circular economy and significantly reduce the consumption of energy, water and land. By 2050, energy, water and land consumption per unit GDP will be down by 60-70% compared to today;

Second, pollutant emissions are reduced in an comprehensive manner and the environment is substantially improved. The environmental carrying capacity for pollutant emissions is different in different periods and countries due to the impact of geography, climate, diffusion conditions and other factors, but undoubtedly, the emission of various kinds of air pollutants in China should be at least 50% lower than the current level, reaching the level of developed countries or that of China in the early-1980s;

Third, natural ecosystems are comprehensively restored, and there is harmonious coexistence between human, nature, and creatures. China will try to construct a scientific urbanization pattern, agricultural development pattern and ecological security pattern and implement several actions, such as the protection and construction of ecological function zones, the construction of national parks, integrated treatment of water and soil loss as well as land desertification, and the protection of bio-diversity.

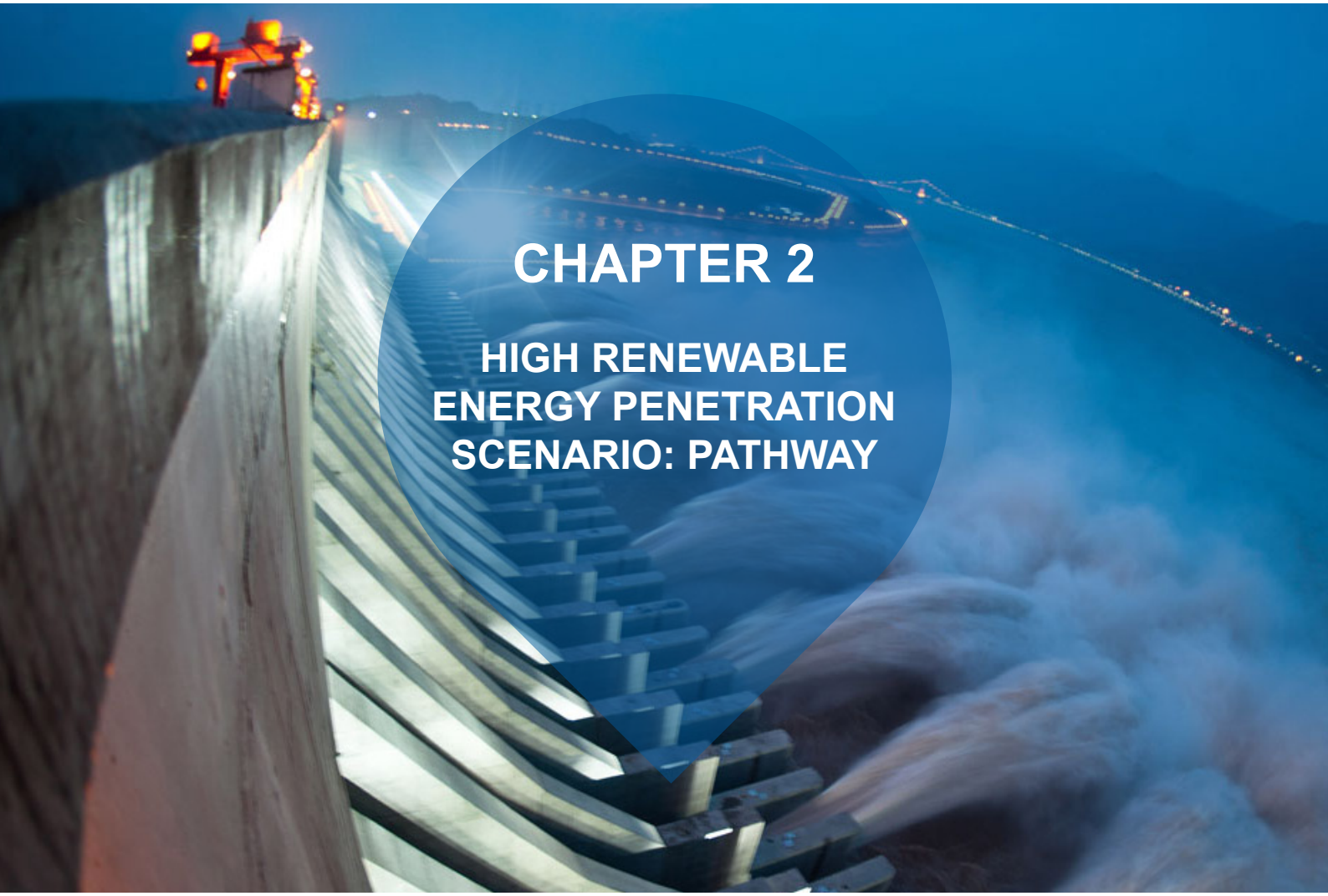
Energy Development – Embrace A Low-carbon and Green Electricity Future

If we take the socio-economic development level of OECD countries in 2010 as the reference for China's 2050 socio-economic development, and base on that to set up China's future energy development path, a reference scenario for primary energy supply will be formulated that includes a shift from today's coal-centered energy structure to a structure in which coal, oil&gas, and non-fossil energy each takes up one third in 2050. In this case, 7 billion tce (tons of coal equivalent) of primary energy supply will be required (fossil energy converted to primary energy based on conversion efficiency; non-fossil energy converted based on calorific value.

Under the high renewable energy penetration scenario, by 2050, China's end-use energy demand is projected to be 3.2 billion tce, in which over 60% is electricity, and primary energy supply will be 3.4 billion tce. The 2050 energy system in China will be highly efficient.

Higher electrification rate enables renewable energy utilization to grow to a higher level. In the high penetration scenario, electricity will account for over 50% of China's total end-use energy consumption; total electricity consumption will increase to 13.5-15 trillion kWh and per capita 10,000-11,000 kWh. Putting electricity at the central position of realizing high renewable energy penetration is objectively determined by electricity characteristics, resource endowment and energy development law.

Electricity drives digital information technology and communication technology, and plays an important role in supporting sustainable economic development. Electricity has become an important cornerstone of the information age. Electric energy has covered virtually all regions of the world through transmission networks and storage devices. Electricity usage marks the advancement of the human civilization, and the usage rate of electric energy is also a scale that measures the socio-economic development level of a country. Electricity will surely become an important driving force of the energy consumption revolution in transport, building and industrial sectors as China realizes the development of high renewable energy penetration. Therefore, to realize high renewable energy penetration, we need to prioritize electricity development, and speed up transformation of the power system to emphasize resource sustainability, energy diversification, system flexibility, and consumer-oriented development.



CHAPTER 2

HIGH RENEWABLE ENERGY PENETRATION SCENARIO: PATHWAY

1 By 2050, Renewable Energy Will Meet 60% of the Primary Energy Demand

China is home to a variety of renewable energy resources with rich reserves. Under the high renewable energy penetration scenario, China's end-use energy consumption in 2050 will be 3.2 billion tce and electricity will account for 62%. China's electrification rate will be up by 36 percentage points from 2010. Among end-use energy consumption, 900 million tce will be directly consumed fossil energy; non-fossil energy will account for 66% and renewable energy 60%. With regard to power supply, 91% of power generation will be from non-fossil energy and 86% from renewable energy. The primary energy supply will be 3.4 billion tce, of which, 62% will be from renewable energy. Energy consumption per unit of GDP will be 0.12 tce/10,000 yuan and energy efficiency will increase by 90% from 2010.

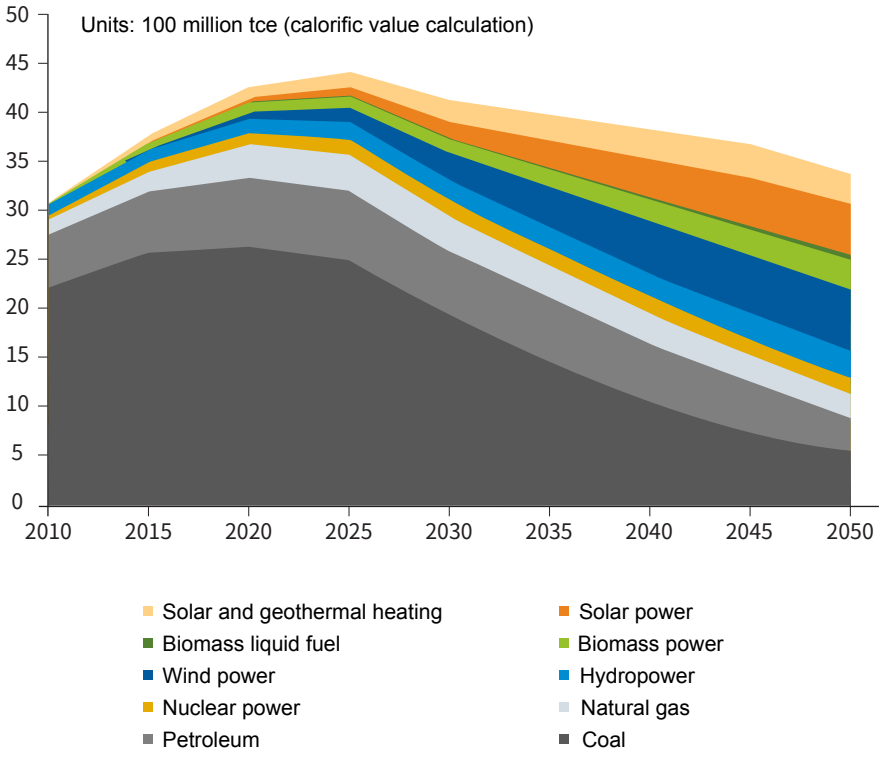


Figure 3 China's Primary Energy Consumption

The 2050 energy system will be defined by two features. First, the electricity-dominated energy supply system will lead to a large increase of energy efficiency and a sharp decline of the emission of various pollutants and CO_2. Second, with regard to power supply, 91% of power will be generated from non-fossil energy, and 86% from renewable energy. When meeting the constraints of the economic development target, primary energy supply under high renewable energy scenario will be 51% lower than under the reference scenario in which 2/3 of the primary energy is fossil energy. As such, total primary energy supply will decline from 7 billion tce in reference scenario to 3.4 billion tce, thus ensuring that the emission of various pollutants in 2050 will be no higher than that recorded in 1980 and carbon emission intensity will be compatible with China's economic scale and population in 2050.

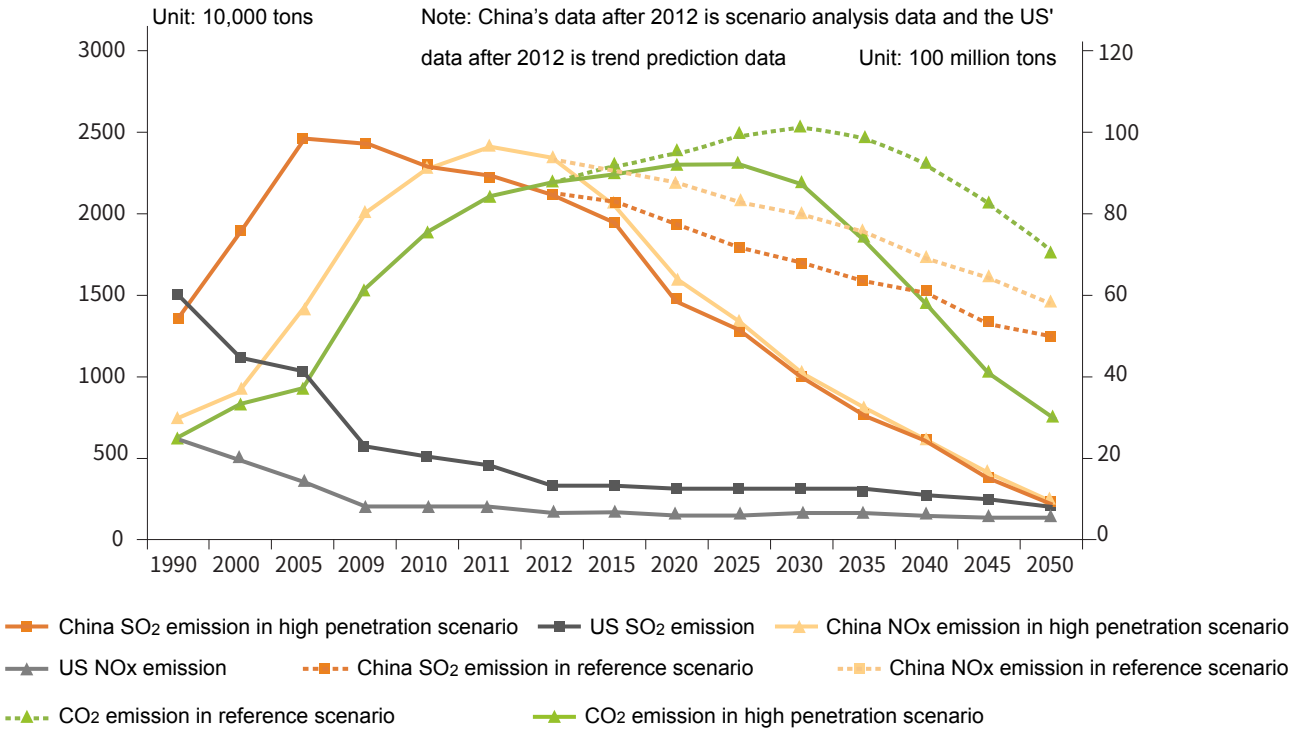


Figure 4 Emission of Major Air Pollutants in High Penetration Scenario and Reference Scenario

2 High Renewable Energy Penetration Will Promote Fossil Energy Consumption and Carbon Emission to Peak by 2025

Under the high renewable energy penetration scenario, coal consumption peak will be reached before 2020. Thereafter, fossil energy consumption peak will be realized by 2025. The replacement of coal-fired power generation by renewable energy power generation will highly reduce coal consumption. Electricity, coking (iron and steel), and manufacturing are the three largest coal-consuming industries in China. Under the high penetration scenario, the proportion of renewable energy power generation in the electricity mix will reach 86%, greatly reducing coal consumption, and will promote power coal to peak at 1.45 billion tce in 2020 and then decline year by year after that. By 2050, coal consumption in power sector will be only 280 million tce. At the same time, by replacing traditional blast furnaces in iron&steel industry with electric furnaces (which make steel using scrap iron & steel) and taking other measures, coal consumption in coking industry will be reduced to 120 million tce in 2050. Therefore, coal consumption will peak at 2.65 billion tce before 2020 and drop to 580 million tce in 2050, accounting for 17% of total primary energy. Although oil and natural gas consumption will increase, fossil fuel consumption will reach the peak value of about 3.7 billion tce between 2020 and 2025.

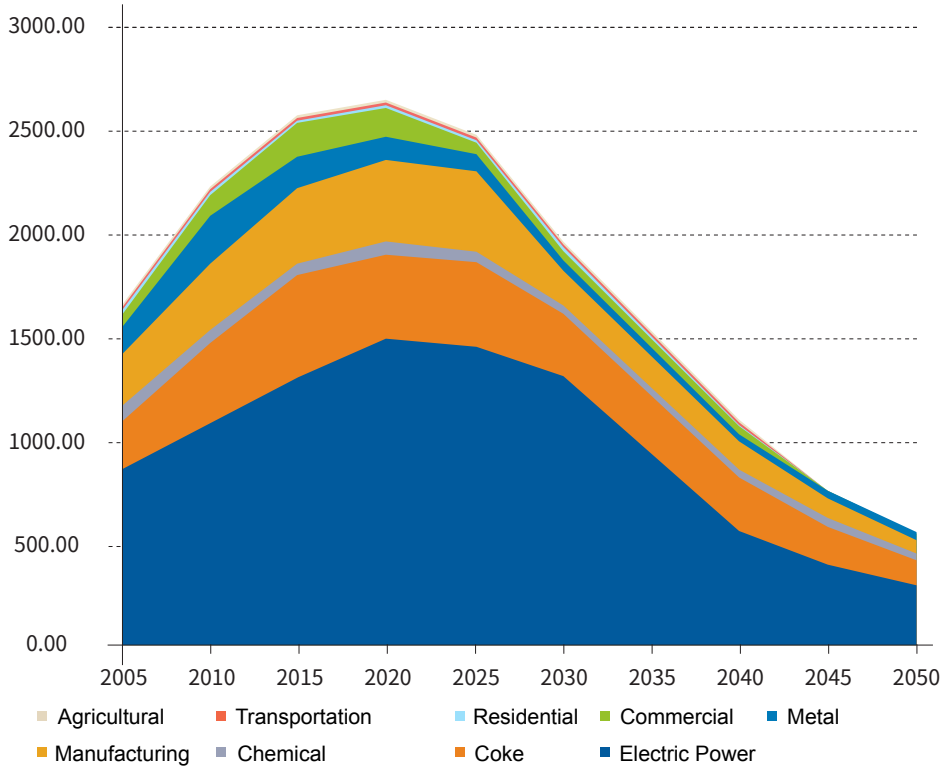


Figure 5 China's Coal Consumption by Sector in High Penetration Scenario (million tce)

China has made the commitment to peak CO_2 emission before 2030. The high penetration scenario will further drive carbon emission to peak earlier in 2025 and at lower value of 9.23 billion tons, and then decline constantly to 3 billion tons by 2050, taking up 20% of the world's total compared to 1/3 in reference scenario.

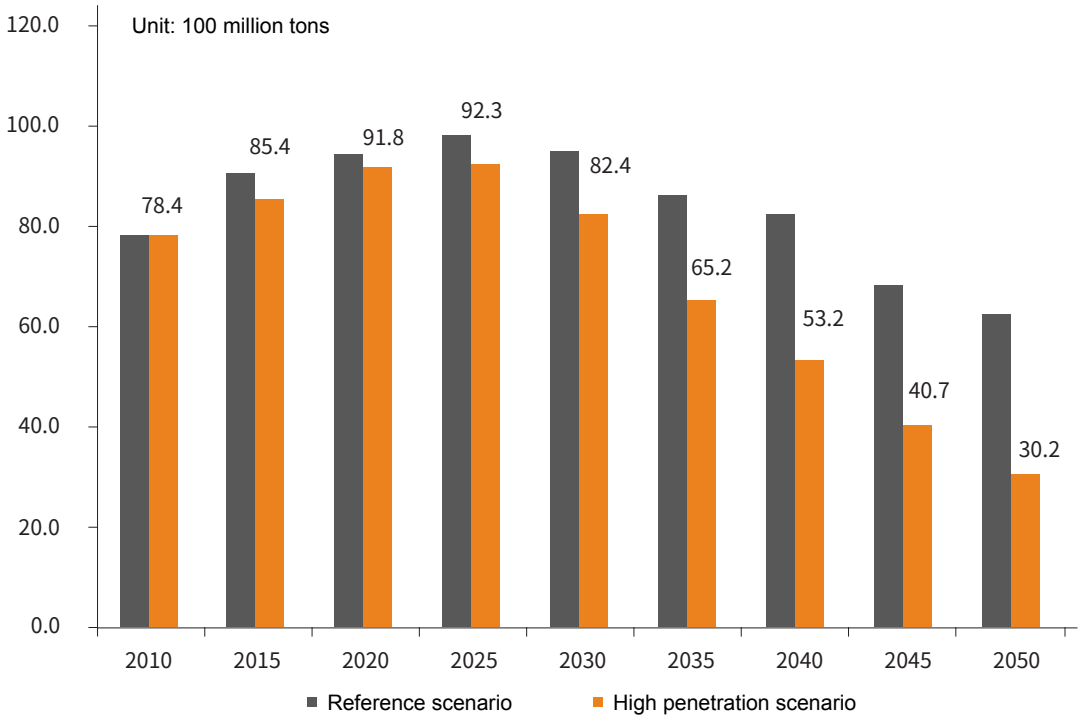


Figure 6 China's CO_2 Emission

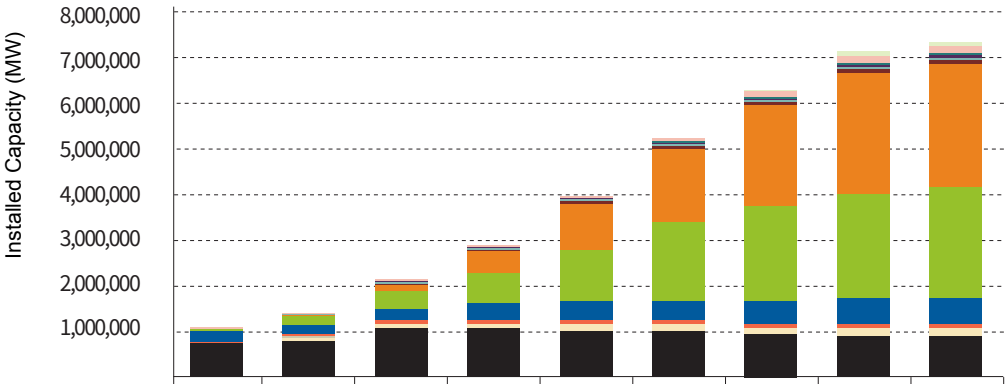
3 Renewable Power is the Essential Replacement for Fossil Energy

This study looks into the power sector development scenario under a fixed socio-economic development goal. The high penetration power scenario could be a realistic route of China's power development in the future.

The high renewable energy penetration scenario considers enhanced environment constraints. The power system expansion route that meets resource, environmental and ecological constraints will be selected through technical and economic optimization. It assumes that economic development mode, power source structure, energy saving and emission reduction technology, as well as the way of living will see major improvements. By mainly relying on domestic energy resources, the high penetration scenario could be realized with the great efforts.

The high renewable energy penetration power scenario enables China to solely rely on its domestic energy resources and maximize renewable energy utilization. China will increase investment in the renewable energy industry and grow it into a new economic growth point and green employment opportunity. China will become a world leader in renewable energy technologies, such as offshore wind power, low-speed wind power, distributed solar power and concentrating solar power (CSP).

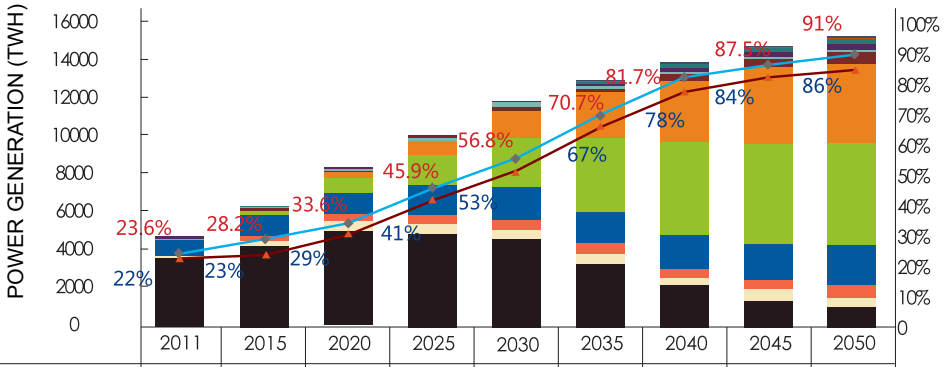
Based on commercialized power generation technology, the share of power generated from non-fossil fuel will be significantly increased. By 2050, the proportion of renewable energy power generation will rise from 46% under reference scenario to over 85% under the high renewable energy penetration scenario. The amount of power generated from non-fossil energy will account for 91% of China's total power generation, and the share of coal-fired power generation will drop from 75% in base year to less than 7% under the high penetration scenario, while meeting the hourly power demands across China. China’s total installed power capacity will reach 7.1 billion kW, including 880 million kW of coal-fired power, 220 million kW of natural gas power, 100 million kW of nuclear power, 550 million kW of hydropower, 2.4 billion kW of wind power, 2.7 billion kW of solar power, 210 million kW of biomass power, 140 million kW of pumped hydro storage power and 160 million kW of chemical energy storage. Wind power and solar power will become China’s backbone energy technologies under the high renewable energy penetration scenario.



	2011	2015	2020	2025	2030	2035	2040	2045	2050
Chemical energy storage							47,179	106,061	158,525
Pumped hydro storage	29,608	38,490	50,038	65,049	81,311	93,508	107,534	123,664	142,213
Ocean energy						1,000	1,000	1,000	1,000
Geothermal power						3,750	11,250	11,250	11,250
Wood pellets power		1,100	1,980	3,221	4,955	8,200	12,329	27,465	32,854
Straw and stalk power	3,402	6,738	11,250	15,573	24,431	38,345	50,110	58,084	61,047
Biogas power	382	16,192	39,306	39,304	39,304	39,306	33,730	34,681	39,306
Municipal waste power	2,011	5,040	8,400	12,574	18,899	33,484	54,215	72,544	80,857
Solar power	3,763	42,025	157,025	500,235	1,048,858	1,657,055	2,206,333	2,678,200	2,696,164
Wind power	48,350	114,880	317,088	632,176	1,103,944	1,663,348	2,092,248	2,287,630	2,396,591
Hydropower	230,670	267,099	313,973	402,363	440,752	460,800	471,881	512,000	554,140
Nuclear power	12,570	42,790	50,500	64,000	66,000	69,000	78,000	85,000	100,000
Oil power	1,224	1,166	1,139	1,098	1,012	862	824	824	824
Natural gas power	32,649	94,273	110,355	125,909	130,119	156,818	173,119	191,750	219,834
Coal power	749,062	822,495	1,083,388	1,079,878	1,052,150	1,037,588	972,299	928,534	886,691

Figure 7 Power Installed Capacity in High Penetration Scenario

China's total power generation will be 15.2 trillion kWh in 2050 under the high renewable energy penetration scenario, including 1038 billion kWh of coal power, 466 billion kWh of natural gas power, 649 billion kWh of nuclear power, 2187 billion kWh of hydropower, 5350 billion kWh of wind power, 4130 billion kWh of solar power and 1100 billion kWh of biomass power. Renewable energy will account for 85.8% of total power generation and non-fossil energy 91%.



	2011	2015	2020	2025	2030	2035	2040	2045	2050
Ocean energy						4	4	4	4
Geothermal power						30	90	90	90
Biomass pellets power		6	12	18	28	46	80	180	202
Straw and stalks power	10	20	59	87	129	187	244	283	297
Biogas power	1	63	118	118	118	118	111	126	139
Municipal Solid Waste power	12	30	50	75	112	197	315	413	462
Solar power	5	61	228	718	1496	2445	3400	4214	4310
Wind power	97	252	753	1513	2595	3904	4741	5130	5350
Hydropower	889	1031	1221	1620	1794	1790	1851	2014	2187
Nuclear power	88	300	354	449	463	484	544	569	649
Oil power	2	2	2	2	2	2	2	2	2
Natural gas power	67	267	522	559	563	553	524	467	466
Coal power	3508	4223	4994	4868	4566	3263	2018	1387	1038

Figure 8 Power Generation under High Penetration Scenario

Under the high renewable energy penetration scenario, the renewable energy deployment model (EDO) optimizes the deployment of commercialized technologies under different levels of renewable energy development, and fully demonstrates the diversity of geographical distribution and time distribution in which renewable energy is generated. The contribution of onshore wind power is the most prominent, while offshore wind power is playing an increasingly important role in realizing high renewable energy penetration. Among solar power technologies, open field photovoltaic (PV) power station plays a more prominent role than distributed solar. Under the high renewable energy penetration scenario, CSP installations grow rapidly, largely because CSP with heat storage can offer greater adjustability. Biomass power generation also has a place in the renewable energy mix, as there will be a shift from forest and agricultural biomass power stations to municipal waste power plants along with the increase in the proportion of renewable energy power and the demand for raw materials of biomass liquid fuel. Given resource and techno-economic constraints, geothermal energy and ocean energy contribute less than other renewable energy, especially under the high renewable energy penetration scenario.

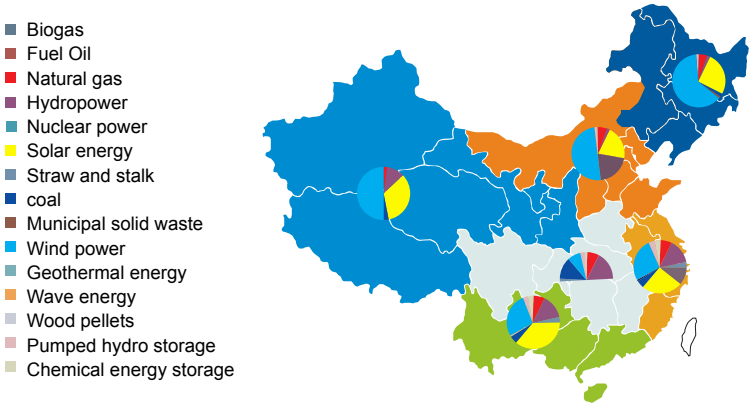


Fig.9 2050 Renewable Energy Installed Capacity by Region in High Penetration Scenario

4

Wind Power and Solar Power Will Become Important Pillars of the Future Power Supply

By 2050, 2.4 billion kW of wind power and 2.7 billion kW of solar power will be installed with a total annual output of 9.66 trillion kWh, which accounts for 64% of China's total power generation. Wind and Solar will therefore become the main power sources provided by the future green electric system. Thanks to technological breakthroughs, cost reductions and comprehensively deepening power sector reforms, wind power and solar power generation will realize dramatic development between 2020 and 2040, and an average of close to 100 million kW of installed capacity will be added every year.

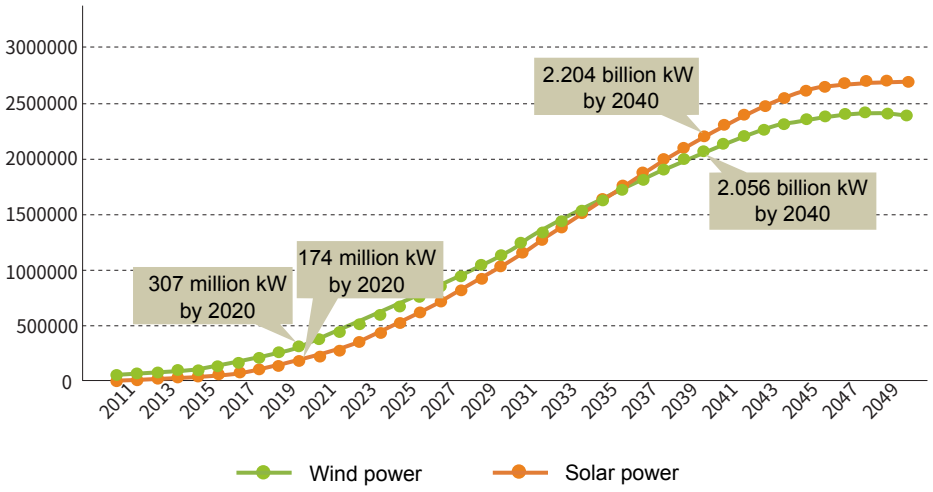


Figure 10 Development Phase Diagram of Wind and Solar Power under High Penetration Scenario

Various areas of the country have the ability to develop wind power and solar power on a large scale. Before 2020, given basic power grid conditions and possible transmission constraints, the main goal is to develop a large-scale wind power market and industrial system that satisfies advanced technical standards and codes, with onshore wind power at the core and intertidal and nearshore wind power to supplement. The newly installed capacity of wind power will reach 25-30 million kW each year. By 2020, the total installed capacity of wind power will reach 250 million kW. By that time, the cost of wind power will become competitive with that of coal power, excluding the cross-provincial power transmission cost; wind power will account for 11% of China's total installed capacity and provide 5% of power supply.

Under a high renewable energy penetration scenario, the economic advantages of wind power will become visible before 2030. The market size of wind power will expand with the simultaneous development of onshore and offshore wind. Newly installed wind capacity will be around 80 million kW each year, accounting for roughly 50% of China's total annual installed power capacity. As for onshore wind facilities, the focus is to build large wind power stations in North China, Northeast China and Northwest China, which will account for over 70% of total installed wind power capacity. Distributed wind power in Central China and East China will develop more rapidly during this period. Offshore wind power resources provide an additional option for coastal provinces like Hebei, Shandong, Jiangsu, and Zhejiang. By 2050, the installed capacity of offshore wind power will amount to 300 million kW. By 2030, the accumulated installed capacity of wind power will surpass 1.1 billion kW, becoming an important contributor for meeting power demand, improving energy mix and supporting national socio-economic development. By 2050, the total installed capacity of wind power will amount to 2.4 billion kW.

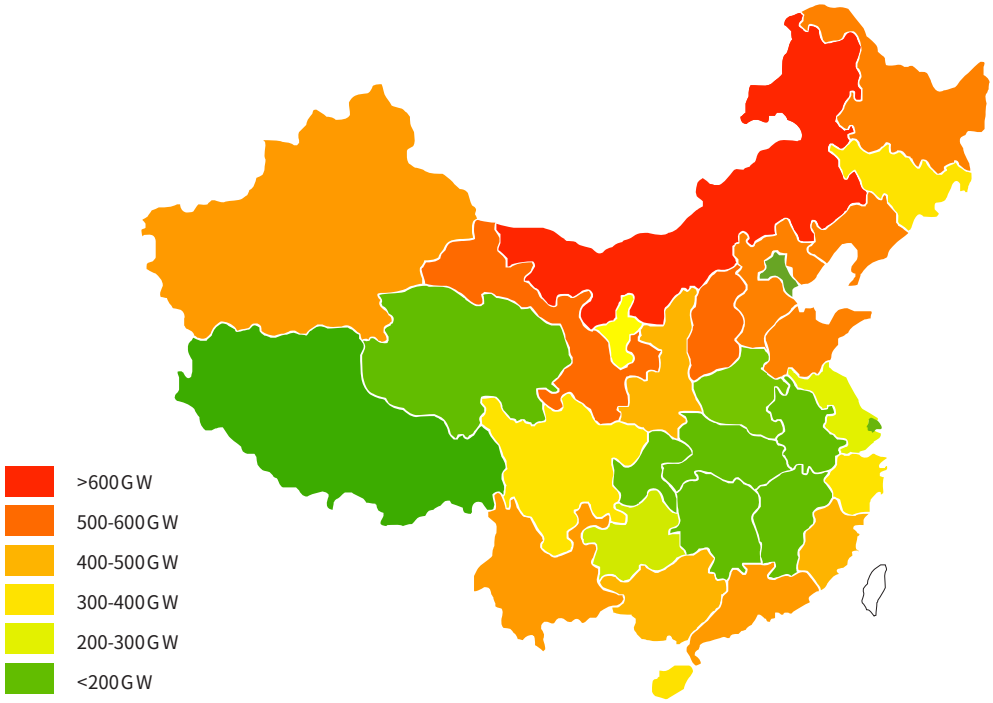


Figure 11 Layout of Wind Power Development in 2050

Solar energy is China's most abundant renewable energy resource, particularly in western China. Before 2020, the average annual growth rate of the PV market will be around 35%, while by 2020, the installed capacity of PV power will be around 130 million kW. The average annual growth rate will be maintained at 25-30% between 2020 and 2030, and by 2030, the installed capacity of solar power under the high penetration scenario will reach 1.05 billion kW. Through large-scale development of CSP, China will have developed mature solar parabolic trough and solar power tower industrial chains. The cost of CSP will be on a constant decline, and by 2030, the installed capacity of CSP will be 50-100 million kW.

The economics of solar power generation will become more pronounced between 2030 and 2050 and its proportion in the power mix will increase rapidly. Under the high penetration scenario, the installed capacity of solar power will amount to 2.7 billion kW in 2050, including 1.9 billion kW of open-field PV power stations and 350 million kW of CSP. Distributed PV power will have big potential too, reaching about 260 million kW.

Based on the distribution of population without access to electricity, solar resources, electricity load, power grid conditions, building roof areas (large industrial parks, commercial clusters and public buildings), and desert/gobi land areas, solar PV power market can be classified into the following types: (1) electricity development and off-grid micro grid projects for providing electricity to areas without electrification, primarily concentrated in China's western provinces and offshore islands; (2) distributed PV power stations mainly concentrated in economically developed provinces in mid-eastern China; (3) large PV power stations, mainly concentrated in 6 provinces in Western China (Tibet, Xinjiang, Inner Mongolia, Gansu, Qinghai and Ningxia) and coastal provinces in Eastern China (Shandong, Jiangsu, Zhejiang, Fujian, Guangdong, Guangxi and Hainan Island). CSP will mainly concentrate in Tibet and five Northwestern provinces.

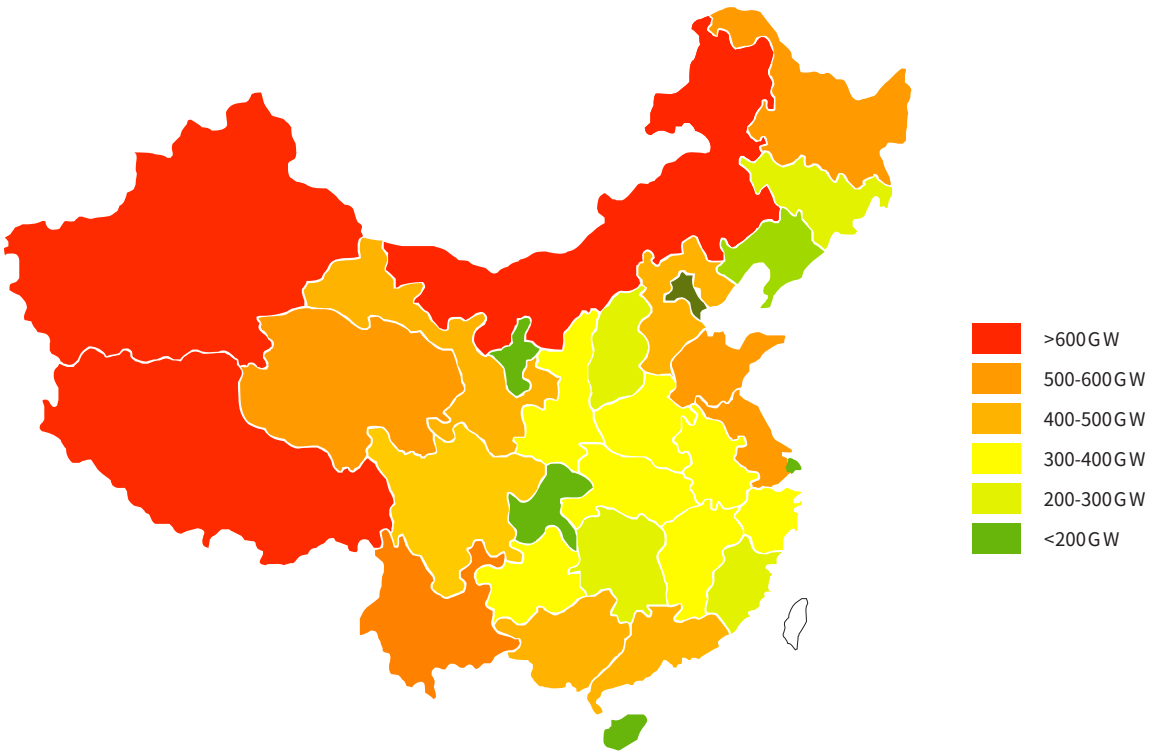


Figure 12 Layout of Solar Power Development in 2050

5 Higher Electrification Rate will Enable Renewable Energy to Grow to a Higher Level

The power system is the core of the future energy system in China. By 2050, electric power will account for over 60% of end-use energy consumption and will become the primary source of energy for people's production and living. China will vigorously promote the utilization of electricity and renewable energy in industry, building, transportation sectors, as well as power and thermal energy production sectors. China will also popularize clean power, solar energy, biomass energy (fuel gas), geothermal energy and other modern renewable energy heat utilization technologies in a comprehensive way, and increase the proportion of electricity in end-use energy consumption.

Under the high penetration scenario, the share of electricity and renewable energy in end-use energy consumption will further increase. By 2050, the total end-use energy consumption will be 3.157 billion tce. Electricity will become the major end-use energy source, meeting 62% of end-use energy demand and accounting for 61% of primary energy supply. 77% of all primary renewable energy will be used in power generation.

Industrial sector: The goals here are to accelerate industrial technology upgrade and large-scale utilization of renewable energy technologies; significantly reduce energy consumption in various industrial processes through electrified and mechanized production; replace fossil energy with electricity and renewable energy, and strictly control the total consumption of fossil energy. By 2050, the energy efficiency of various parts of China's industrial sector will be up to the energy efficiency levels of developed countries. Under this scenario, the industrial sector will play an important role in the improvement of energy mix.

Building: Building sector will largely utilize solar energy, biomass, and geothermal energy for heating, and the proportion of fossil energy will decline year by year. Heating will be provided for buildings through district heating, community boilers, heat pumps, and renewable power. Under the high penetration scenario, the era of coal heating will end, and low-carbon and even zero emission buildings will become common.

Transportation: Under the high penetration scenario, China's production and sales of new energy vehicles in 2020, including pure electric vehicles, plug-in vehicles, and fuel cell vehicles, will reach 2 million, and electric vehicle stock will amount to 5 million. New energy vehicles, represented by electric vehicles, will be popularized rapidly and the sales volume will surpass that of engine-fuel vehicles before 2035, becoming the mainstream vehicle power technology. By 2050, the ownership of pure electric vehicle, plug-in hybrid electric vehicle and hydrogen cell vehicle will account for 86% of the vehicle market.

Social civilization: Electricity is a kind of energy with the highest use efficiency yet without any emissions among all end-use energy varieties. The electrification level of a country, that is, the level of electricity use in production, living and mobility, represents the degree of civilization of that country. By 2050, more than 80% of kitchen work of Chinese residents will be completed mainly via electricity. The future era is an information era with a high-degree integration of communication, energy, and logistics over the Internet, and that calls for the support of high electrification rate.

6 Transform the Electricity Transmission Network to a Platform for Optimizing Resources Allocation

With the increase of renewable power generation, new transmission will be needed to transmit power from western and northern China to load centers in eastern China, and to share electricity reserves and smooth out variability of renewable power output over a wider geographic area. Increased transmission infrastructure will help realize power transmission and electricity sharing within a larger area, increase system flexibility and balance changes in wind power and solar power output and power load. As variable power generation is developed and utilized on a large scale, the net load (load minus variable power generation) of some specific regions will demonstrate drastic changes. Regional interconnection and the geographic expansion of balancing areas will be helpful to reduce the changes in net load because a wider balance area allows the system to schedule and utilize large amount of renewable energy resources and more diversified power technologies, and make the output and load in wider region smoother. Under the high renewable energy penetration scenario, there will be three cross-regional transmission lines with a capacity of more than 100 million kW - the Northwest-Central China line, Central China-East China line and North China-East China line. New transmission capacity required under high renewable energy penetration scenario is higher than that of reference scenario, and transmission demand will grow as renewable energy power increases.

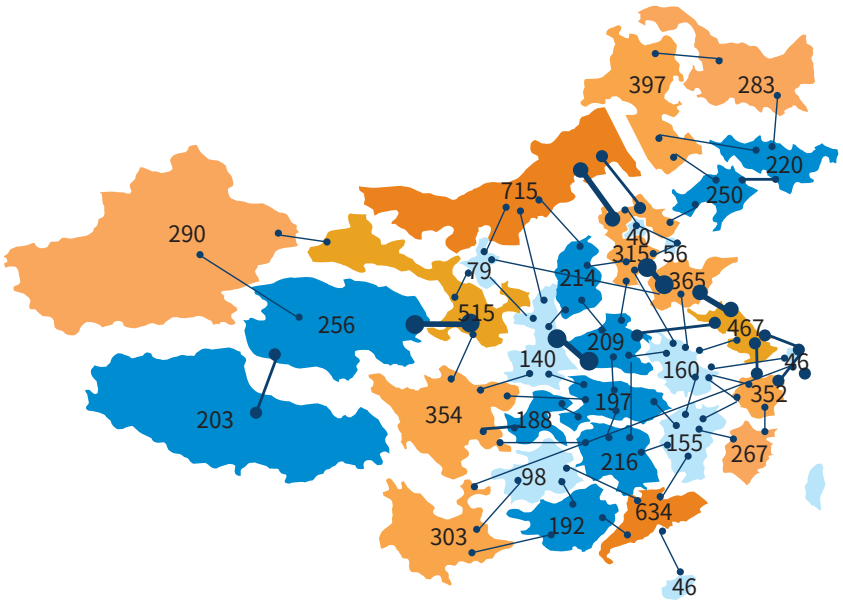
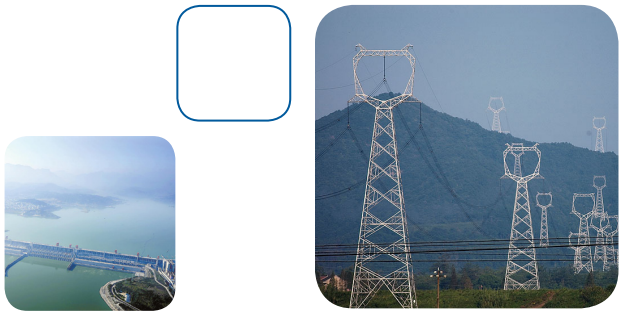


Figure 13 Inter-provincial Transmission Capacity Demand and the Total Installed Capacity of Each Province (GW) under High Penetration Scenario



Additional long-distance electric power transmission capacity is an important feature of the high renewable energy penetration scenario in the future. Power production simulation and power flow analysis demonstrates that east-west transmission have dual direction to flexibly respond to temporary changes in power supply and demand. The expansion of power transmission line makes eastern load better connect with high quality renewable energy resources in western China. For now, major challenges still yet to be tackled, including difficulty in siting and land acquisition for building new transmission lines, transmission cost allocation, and coordination among regulatory authorities, which have restricted the expansion of power transmission line on a large scale.

This study finds that new transmission under the high renewable energy penetration scenario will concentrate in China's middle and western regions and will be mainly used to connect the high quality wind power and solar power resources in the central and western regions and transmit that renewable energy power to load centers in eastern China.

Figure 14 Cross-regional Transmission Capacity Demand under High Penetration Scenario

7 Technological and Institutional Innovation is the Foundation to Build a High Renewable Energy Penetration Power System

Under the high renewable energy penetration scenario, planning and operation of the power system will be subject to many challenges, including managing low demand and curtailing excess power generation, among others. Analysis shows that contrary to the existing fossil fuel-centered power system, where challenges mainly focus on peak load (such as a summer afternoon), the operational challenge under the high renewable energy penetration scenario is the most daunting during periods of low demand (such as a spring evening), because during such times, renewable energy power generation exceeds demands, forcing thermal generators to reduce output to the minimum power generation level. During periods of low demand with the current system under the reference scenario, most down regulation demands could be met by adjusting coal power and hydropower generator output. Although gas turbines need to be operated, the demand is lower than that under the high penetration scenario. However, during periods of low demand under the high renewable energy penetration scenario, high renewable power output will lead to severe variability of the net load (load minus wind power and solar power). The increase in net load variability will bring about challenges related to improving peak regulating capacity and system flexibility.

Under the high renewable energy penetration scenario, wind, solar and hydropower curtailment will be reduced through a series of technical and institutional measures. First, China will upgrade the capacity of the transmission system to alleviate congestion, and reduce curtailment; second, China will emphasize energy storage technologies and help reduce the capacity of online power generators that provide spinning reserve; decrease the number of power plants that run at the minimum level, and reduce the curtailment of renewable energy power generation; third, China will increase the flexibility of thermal generators, and encourage flexible generators to operate more often; fourth, China will increase energy storage and controllable load, and enhance system flexibility; and, China will implement power trading through power market; and finally, in spring or during periods of low demand, industries may increase consumption of lower-cost electricity so as to increase demand, and the electricity that would have been curtailed can be consumed instead.

Modeling of the power sector shows that in order to adapt to the increase in renewable power generation, China needs to deploy a more flexible system. System flexibility could be enhanced based on multiple options on the supply and demand side. However, China needs to improve technology, formulate new operational procedures and develop new business models and new market rules. As renewable power generation will increase from 46% in the reference scenario to 85% in the high penetration scenario in 2050, the contribution rate of variable power will rise from 30% to 60%, making it more challenging to maintain the real-time balance between electricity supply and demand. Variability and uncertainty associated with high penetrations of wind power and solar power will be managed by adding flexible power capacity, improving the flexibility of coal power plants, using energy storage devices (including pure electric vehicles) and demand response mechanisms, and expanding transmission infrastructure.

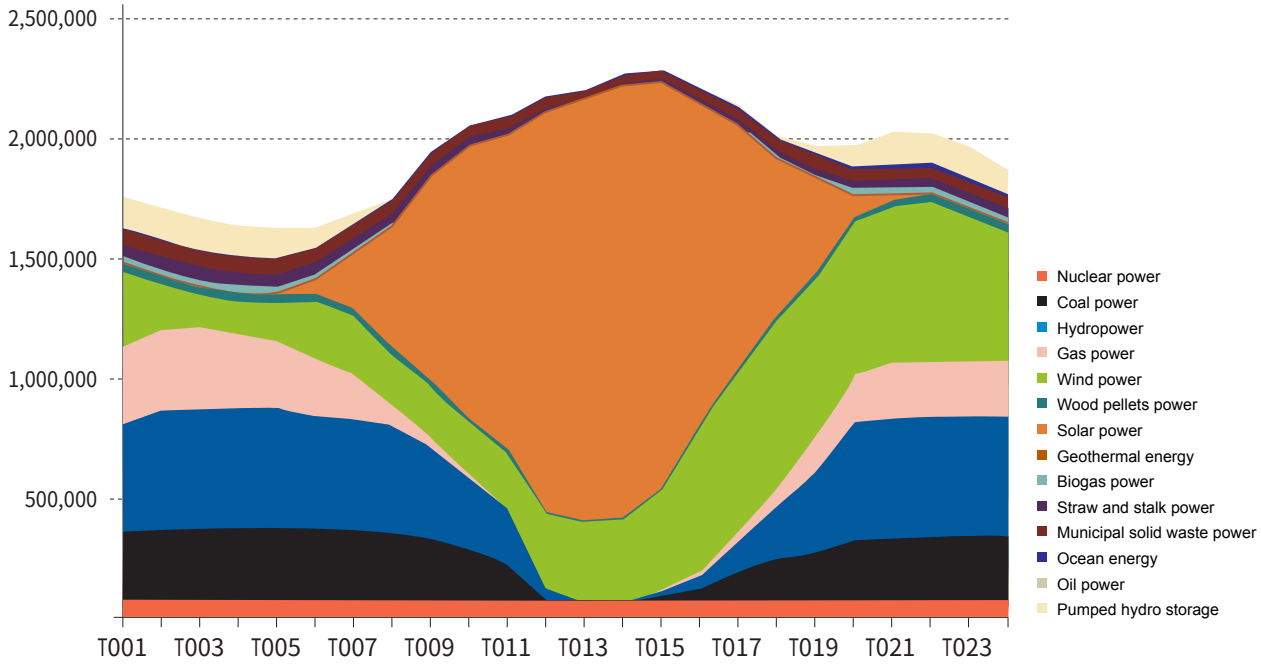


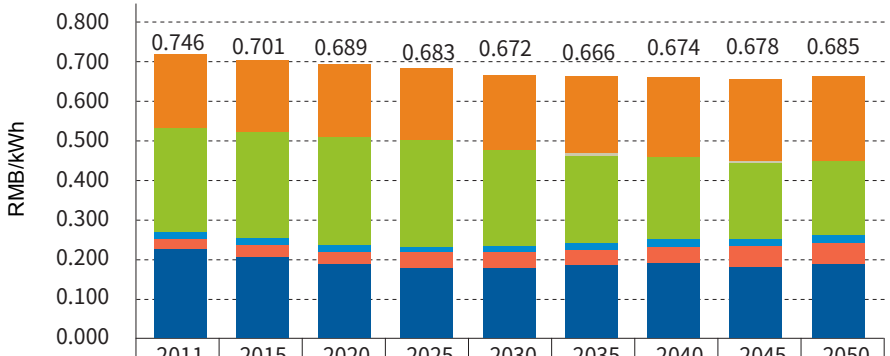
Figure 15 Analysis of the Hourly Dispatch of Nationwide Power Generation on a Typical Day in High Penetration Scenario

By 2050, 85% of China's total power generation will be provided by renewable power, and 60% by variable renewable power such as solar and wind. With the above-mentioned measures, China can balance the hourly power supply and demand in each region. Figure 15 shows the contribution of each type of generation across China on a typical day under the high renewable energy penetration scenario.

8 Building a High Renewable Energy Penetration Power System at a Small or Non-Incremental Cost

This study quantifies and evaluates the average per-kWh cost under different scenarios, including power transmission cost, unit start-up cost, fuel cost, fixed cost O&M, variable cost O&M and capacity cost. The figure below demonstrates the development trend of average per-kWh cost and levelized kWh cost by technology under the high penetration scenario.

Advancements in renewable energy technologies, such as improvements in technology cost and performance have the greatest impact on reducing the incremental cost in high renewable energy penetration scenario. The average cost of the high renewable energy penetration scenario is pretty close to that of the reference scenario. Under the high renewable energy penetration scenario, the average cost per kWh of electricity will rise slightly between 2030 and 2050, basically remaining between RMB0.672/kWh and RMB0.685/kWh, while in reference scenario the average cost between 2030-2050 will stay flat around RMB0.67/kWh.



	2011	2015	2020	2025	2030	2035	2040	2045	2050
Transmission cost	0.180	0.182	0.183	0.186	0.190	0.194	0.199	0.205	0.211
Unit start-up cost	0.000	0.001	0.001	0.001	0.001	0.001	0.002	0.002	0.002
Fuel cost	0.259	0.265	0.269	0.260	0.235	0.220	0.206	0.192	0.185
Variable cost O&M	0.021	0.021	0.020	0.019	0.018	0.017	0.017	0.018	0.018
Fixed cost O&M	0.022	0.027	0.029	0.031	0.035	0.039	0.043	0.049	0.053
Capacity cost	0.229	0.211	0.193	0.189	0.188	0.192	0.194	0.189	0.194

Figure 16 Trend of kWh Cost Development in High Penetration Scenario

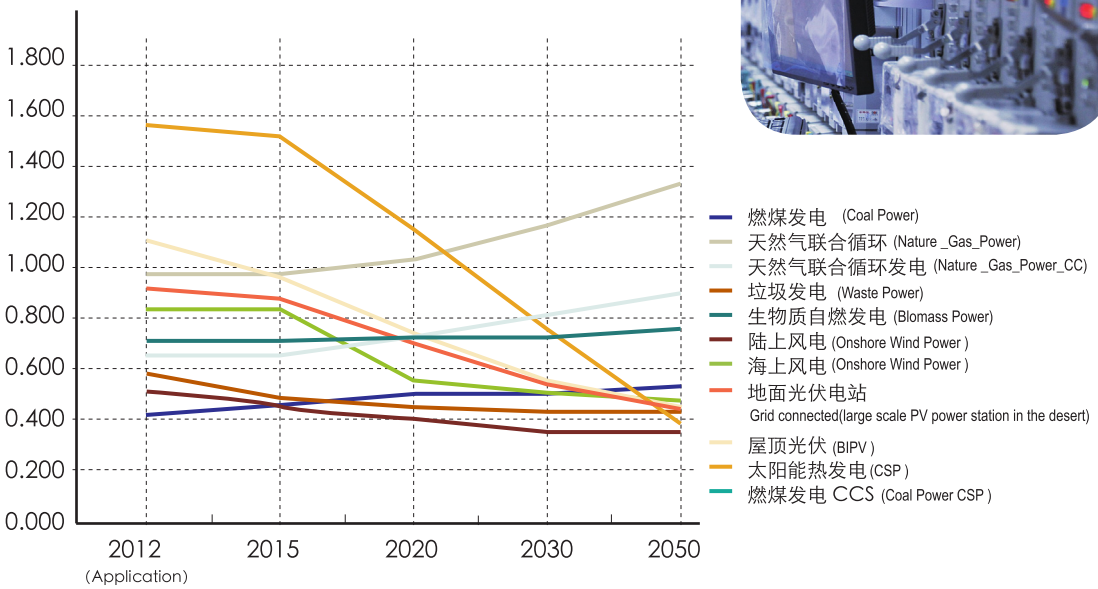


Figure 17 Levelized kWh Cost Development in High Penetration Scenario

Similar to other high penetration studies, the analysis of the per-kWh cost under the high renewable energy penetration scenario shows that fuel costs drop drastically while capacity costs and power transmission costs increase. Major factors contributing to a decrease first and then an increase in relevant costs under the high renewable energy penetration scenario are as follows: capacity cost - existing power plants replace new power equipment (mainly renewable power generation equipment); and the additional cost for gas turbines, energy storage equipment and the construction of power transmission lines. Compared with the reference scenario, most of the incremental capital investment related to these factors will be offset by the reduced fuel costs from fossil energy plants not generating as much as in the reference scenario. Therefore, through constant evolution and improvement of renewable technology, renewable power generation will increase dramatically in comparison with the reference scenario under the premise of a small or non-incremental cost. Furthermore, the analysis of incremental costs doesn't take into consideration the social costs (such as the environmental impact caused by GHG emission and air pollutants) or economic impacts.

9 As a New Economic Growth Point, Renewable Energy Can Significantly Improve the Development Quality of the Overall Economy

Under the high renewable energy penetration scenario, wind power, solar energy, electric vehicles and other emerging industries will become a new economic growth point. China's projected aggregate economic performance will increase from RMB40 trillion in 2010 to RMB280 trillion – a 7-fold increase. In 2050, the contribution of total added value of related renewable energy industries to GDP in 2050 is estimated to increase from a mere 0.9% in 2010 to 6.2% in 2050. The added value of wind power industry will reach RMB3.8 trillion in 2050, 108% higher than RMB1.8 trillion in the reference scenario. The added value of solar power industry will amount to RMB2.8 trillion, nearly 5 times higher than RMB0.5 trillion in the reference scenario. In addition, renewable energy industry's technical and industrial demands for equipment manufacturing, electronic instruments, and weather forecast, etc., will stimulate the manufacturing of machinery, electronic products, research & development (R&D) and service industries. The total added value of the renewable energy industry supply chain will grow to RMB17 trillion, and electric vehicle production will record nearly RMB8 trillion, accounting for 6.2% and 2.9% respectively of GDP and together, contributing more than 9% of GDP.

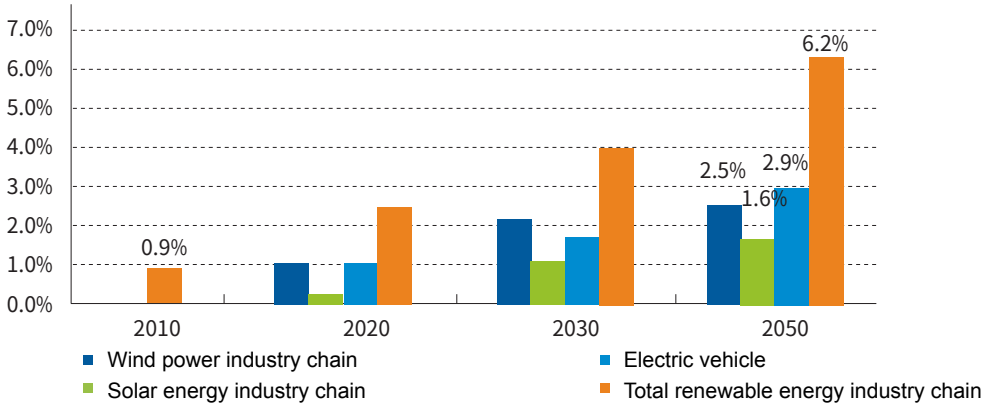


Figure 18 Contributions of Renewable Energy and Related Industries to GDP

In the meantime, the development of more renewable energy plants will create 12 million jobs (in 2050) in the renewable energy industry and related industries. Among others, the number of jobs in solar power generation and heat utilization, PV equipment and other solar-related industries is the highest at 4.8 million, while wind power and related industries reaches 3.8 million. Electronics, R&D, electricity and other supporting industries required by renewable energy development are mainly emerging industries, and high renewable energy penetration scenario will promote the transmission of China's employed population from traditional manufacturing to high value add industries. Research demonstrates that the number of workers in traditional fossil energy industries such as coal mining and washing industry, oil refining industry, and transportation is declining year by year and by 2050; the number of workers in electricity, service, electronic machinery and research industries will increase by 2.61 million, 1.62 million, 1.41 million and 0.96 million, respectively. In the next 40 years, China will minimize the impact on employment of traditional energy sectors by the development of new employment opportunities in renewable energy industries, and the retirement and transfer of staff in some traditional energy industries to other industries after receiving job training and career guidance.

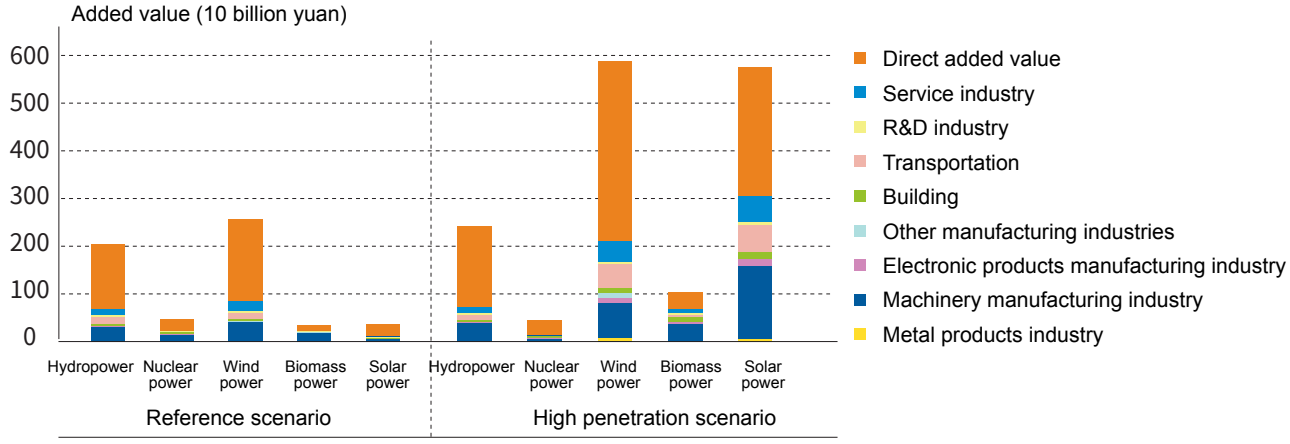


Figure 19 Added Value of Relevant Industries Driven by Renewable Energy in High Penetration Scenario (10 billion yuan)

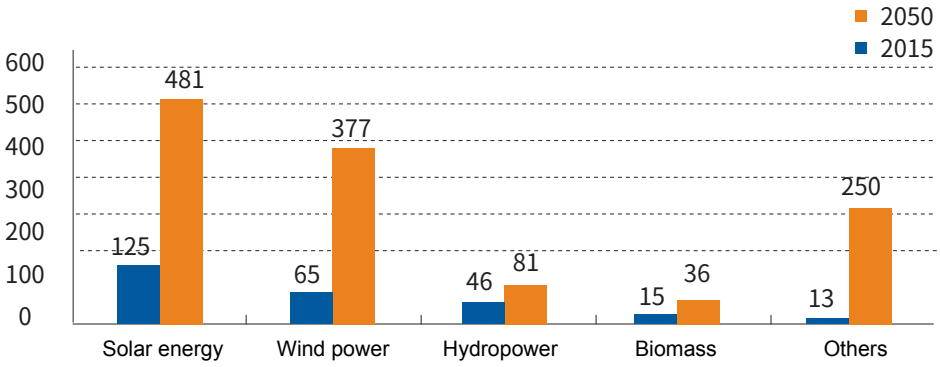


Figure 20 Growth of Employment in Renewable Energy and Related Industries (Unit: 10 Thousand)

In general, the development of high renewable energy penetration has elevated the quality of macroeconomic development in China. Our study results show that compared with the reference scenario, the development of high levels of renewable energy does not negatively impact the economic performance. Instead, renewable energy development actively promotes the adjustment of economic structures and enhancement in the quality of economic growth. For instance, under the high renewable energy penetration scenario, residents' consumption contributes more to GDP, while government spending is relatively smaller, which is beneficial for residents to share the results of economic growth in a more fair and effective way. In addition, the aggregate level of international trade is enhanced, the domestic price level is effectively controlled and the quality of economic growth is further optimized.

Table 1 Impacts of High Penetration Scenario on Marco Economic Indicators (2050, trillion Yuan)

	Reference scenario	High penetration scenario	Change
Residents' consumption	141.2	141.5	+0.23%
Government spending	33.2	32.8	−1.44%
Export	70.5	71.1	+0.87%
Import	69.6	70.2	+0.88%
Price level	0.909	0.908	−0.11%

10 High Renewable Energy Penetration Will Help Bring Back Clear Water and Blue Skies

High renewable energy penetration is expected to replace coal consumption significantly, and by 2050, China's total coal consumption will be less than 600 million tce, only about 1/3 of that as consumed in 2010. Major pollutants and CO2 emitted by the combustion of fossil energy will decrease significantly. According to the modeling results, China's CO2 emission will drop from today's about 10 billion tons to 3 billion tons in 2050, a 55% decline from 6.7 billion tons in 2010. In 2050, projected per capita CO2 emissions will be 2.17 tons, a 51% decline from the world average in 2010 (4.44 tons) and a 46% decline from the world average in 1990 (3.99 tons).

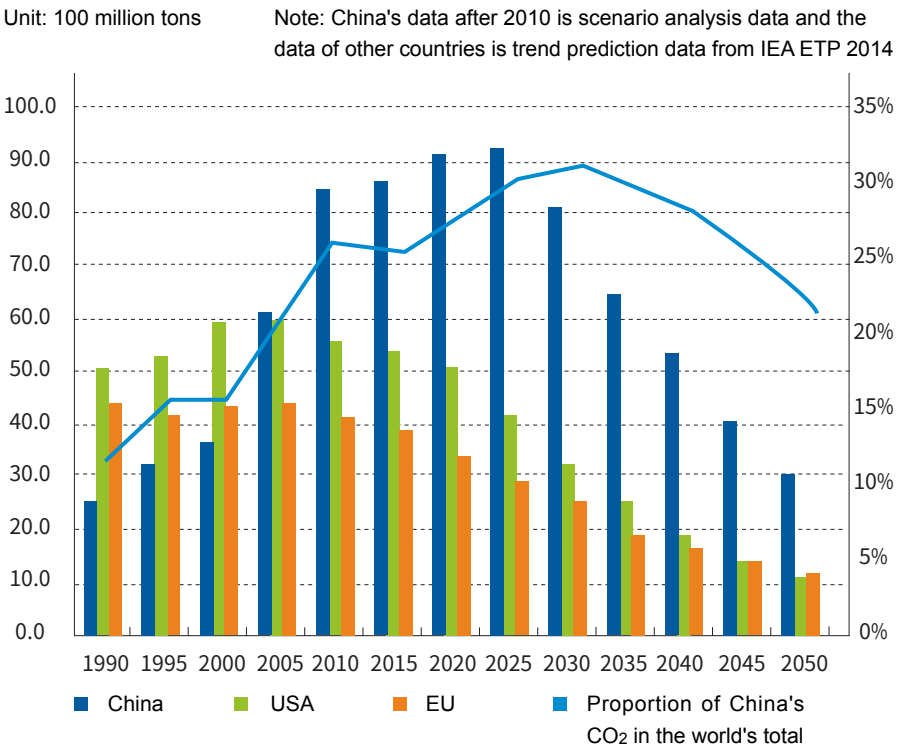
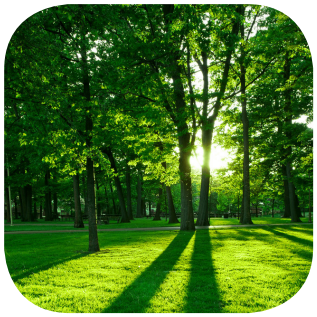


Figure 21 China's CO_2 Emission in the Global Contrast in High Penetration Scenario

If the entire international community could work together to control the temperature rise to less than 2 degrees Celsius, China's CO_2 emission in 2050 will be only about 1/4 of the world's total. Compared with the share of China's GDP in the world's total, China will make a great difference in improving the world's ecological environment. Europe and the United States have made the industrialization journey with large-scale CO_2 emissions. Other studies predict that Europe and


the United States are witnessing the decline of emissions from peak in 2005 to the emission target in 2050. China will reduce its CO_2 emissions in a shorter period by developing high levels of renewable energy that in turn will result in dramatic declines in China's carbon emissions.

China has developed and implemented pollution emission control strategies since the 12th Five-year Plan period. The quantity of SO_2 and NOx emissions of China peaked at 2005 and 2010, respectively, and have since declined year by year. The high renewable energy penetration scenario will further accelerate the reduction in total emissions of major air pollutants, and SO_2 and NOx emissions will be at about 2.5 million tons and 2.7 million tons, respectively. The emission of major pollutants (SO_2, NOx, heavy metal Hg, etc.) will be kept even with 1980 levels. China will witness the restoration of clean water and blue skies.

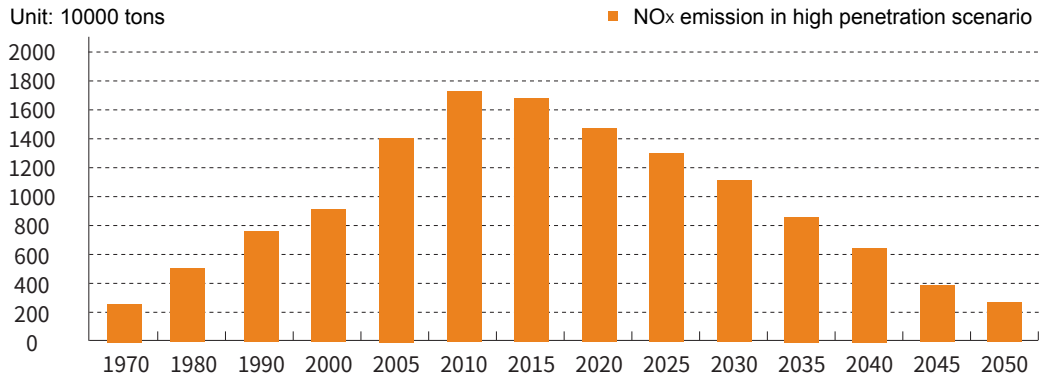


Figure 22 China's NOx Emission in High Penetration Scenario

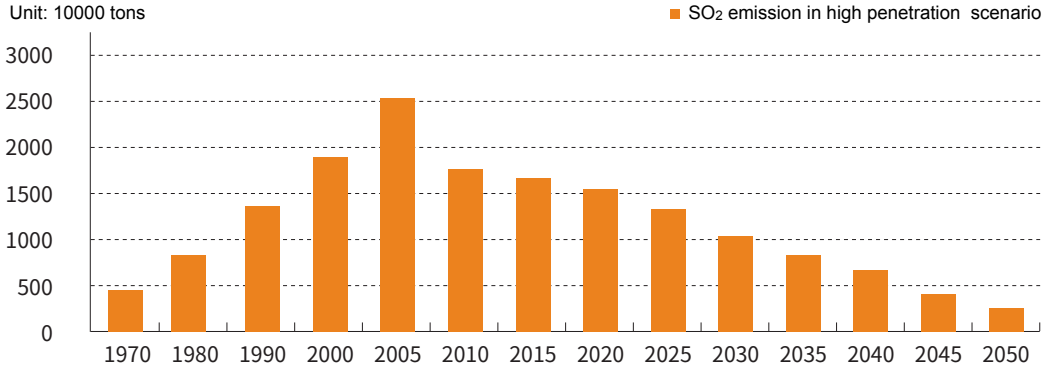
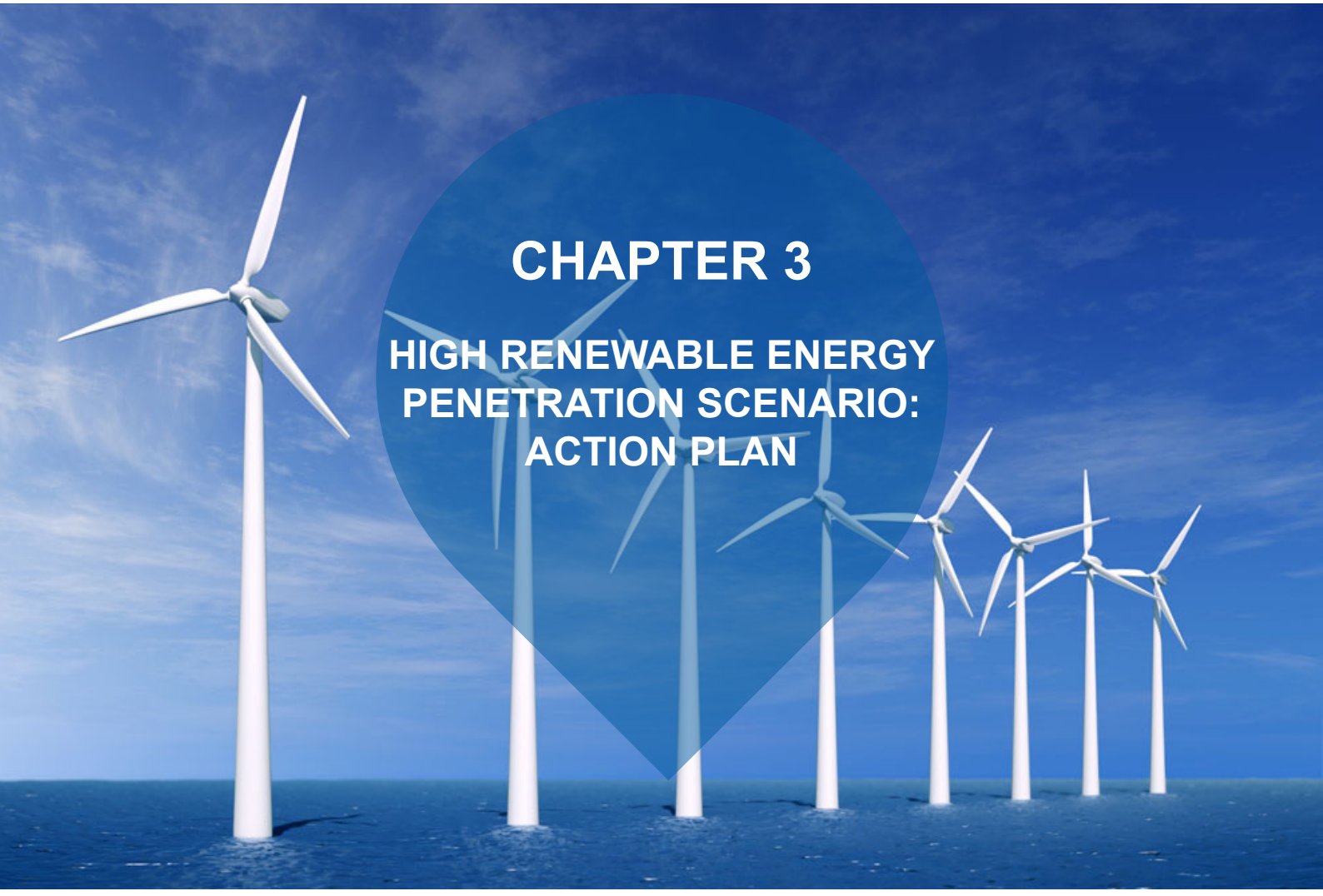


Figure 23 China's SO_2 Emission in High Penetration Scenario

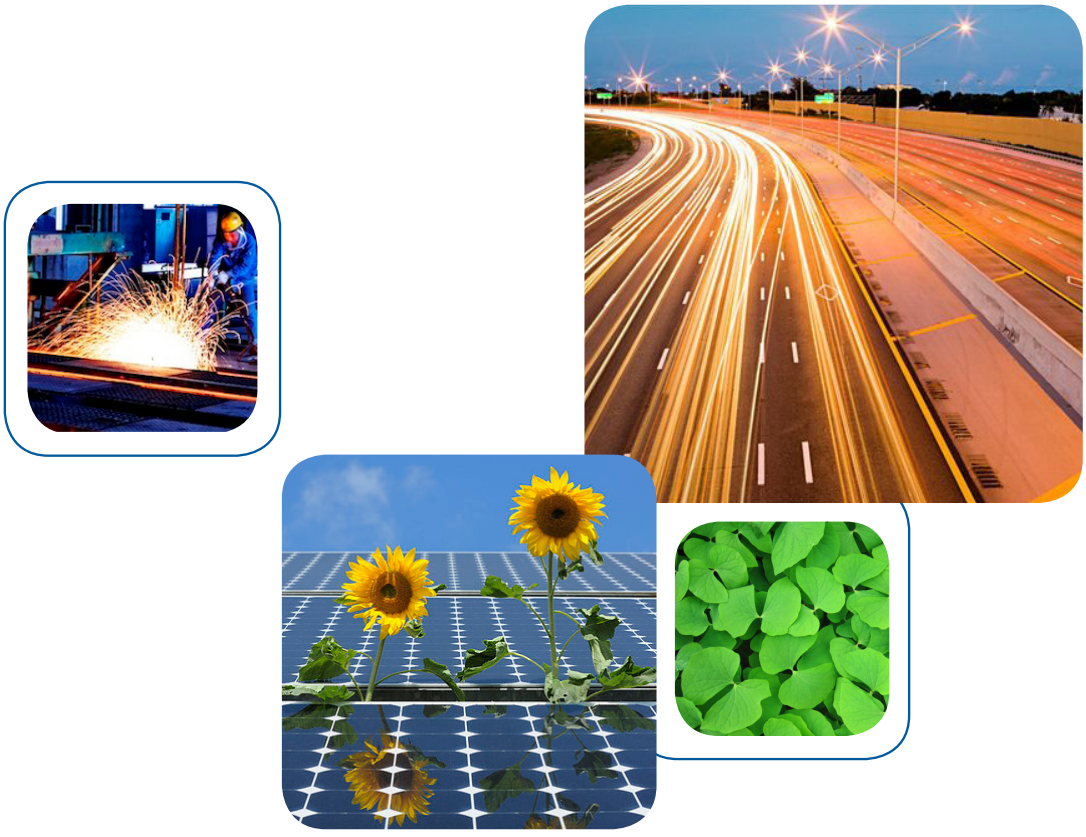


CHAPTER 3

HIGH RENEWABLE ENERGY PENETRATION SCENARIO: ACTION PLAN

In order to adapt to China's future energy transformation, China shall regard the realization of high renewable energy penetration as an important part of the national energy strategy. This objective shall be substantially demonstrated in all energy-related development plans to be rolled out. China needs to formulate a high renewable energy penetration roadmap, break down the general objective into specific objectives at different development stages; prioritize and define tasks in the national energy strategy; and identify necessary conditions, major obstacles, key fields and main jobs to realize high renewable energy penetration at different development stages.

Specifically, government departments shall enhance guidance and promotion in terms of strategic planning and policy management from now to future stages; renewable energy industries shall vigorously pursue technological innovations and the development and utilization of renewable energy; the electricity sector shall adapt to the features of new renewable energy technologies and construct a public grid service platform and work on developing a more flexible power system; the building industry, transportation and other end-use sectors shall advocate the replacement of fossil energy by clean electric power and renewable energy, build urban clean energy systems, and develop a smart energy Internet, thereby jointly establishing the future energy system and realizing the energy revolution.



1 Major Actions of Government

Formulate and Implement Clean Low-Carbon Energy Revolution Strategy and Action Plan, Which Prioritize Renewable Energy

- Government departments will identify the long-term goals and roads for pollutants and CO_2 emissions reductions in the energy sector according to the requirements of the ecological civilization. Government departments shall formulate the strategy of establishing and meeting goals for 2030and 2050, so as to ensure that renewable energy will account for 23% and 60% of primary energy consumption respectively, and that CO_2 emissions from the energy sector will peak before 2025 and decline sharply in 2050;
- Establish and implement strategy and action plans for renewable energy priority development, and develop renewables priority development roadmaps in forms of power generation, heat supply, electric vehicles and biofuel throughout energy production and end-use sectors, so as to increase the penetration level of renewables and enable it to replace new installations of fossil energy in 2020, and phase out existing fossil energy capacity after 2030;
- Implement a target and action plan for controlling total energy consumption, especially total fossil fuel consumption, to ensure that coal consumption, the installed capacity of coal power and oil consumption peaks before 2020, in 2020 and around 2025, respectively;
- Develop and deliver strategies and roadmaps concerning major infrastructure construction, key scientific and technological innovation and major public platforms so as to guide, support and serve industrial development.

Establish Power Market Mechanism Adaptable to Handle Renewable Power

- Government departments will accelerate the development of an electricity price setting mechanism that is based on market competition as well as supply and demand, and use the advantage of renewable energy with zero marginal cost to realize the preferential scheduling of renewable energy. Preferential scheduling will occur after the transitional period of renewable power generation that is preferentially arranged under the existing annual power generation plan;
- Actively introduce multi-department controlled electricity price systems, establish a capacity market and ancillary services market, incentivize the capacity and ancillary services of various market participants, and promote different participants to offer flexible market services;
- Establish inter-provincial regional and national power trading markets, and break down the separation of power markets among provinces and regions and among power grids;
- Set up an independent trading (scheduling) platform, recover the misplaced public rights from utilities (especially power grid companies), and develop and improve the public governance mechanism of the independent power trading and scheduling platform;
- Separate the power transmission and distribution networks, and launch regulatory oversight of power transmission and distribution; and
- IW1mprove demand side response, energy storage and other market management systems that support flexibility.

Improve the Green Tax System and Carbon Trading Market System to Create A Fair Playing Field for Renewable Energy

- Government departments will move forward with transitioning to green taxes, accelerate reforms of resource taxes and implement environmental taxes and carbon taxes so as to ensure that the price of fossil fuel energy will cover resource depletion, the external costs of environmental pollution and to create a level playing field for renewable energy;
- Establish and operate a total carbon emission control and trading system, promote the paid issuance of emission permits on a larger scale, gradually tighten carbon emission constraints, and promote the mark-up of fossil fuel use costs and the shift of major players under emission controls to renewable energy utilization;
- Increase support for funding of renewable energy and other clean and low-carbon energy by using resource taxes, environmental taxes and the proceeds of auctions of carbon emission permits in the short and medium term.

Establish Sound Systems of Legal Protection, Comprehensive Management and Professional Regulation Adaptable to Renewable Energy Development

- Government departments will ensure lawmaking goes first, promulgate Energy Law, revise Electricity Power Law and improve Renewable Energy Law, clarify the preferential development position and key mechanisms of renewable energy at different levels, and enhance legal protections on the preferential development of renewable energy and institutional transformation;
- Strengthen comprehensive management functions and implementation effect, significantly enhance integrated and scientific planning to guide, regulate and coordinate China's energy development, and break geographic market barriers. All these will jointly promote comprehensive energy development nationwide and safeguard priority development of renewable energy and new energy;
- Move forward with the reform of an investment management system for renewable energy projects, adapt to the features of renewable energy projects, including smaller-scale and diversified investment, construction and operation, broaden access to project investment, promote and attract investment develop more renewable energy project; and
- Establish modern and specialized energy and electricity supervision systems. Additionally, government departments will reform the traditional way of supervision, put in place a professional supervising pattern that is formal, standardized and digital, that matches with comprehensive energy management; and consolidate such reforms as laws, regulations, standards and supervisory systems.

2 Major Actions of Renewable Energy Industry

Build Major Public R&D Platforms, Strengthen Technology R&D, and Accelerate Industrialization Process

- The renewable energy industry will develop a resource database and atlas, and provide refined evaluation results of wind power, solar power and other renewable energy resources;
- Create a public technology platform, including public technology R&D and service platforms for wind power, solar power, and the micro power grid;
- Promote technological R&D, especially facilitating the R&D, demonstration, promotion and application of core and key technologies, including efficient wind power, solar power generation, biomass power generation, and integrated application of medium-high temperature solar heating.

Keep Sustained Large-scale Development of Renewable Power Generation

Hydropower: improve the management, residents resettlement and ecological environmental protection systems and mechanisms; constantly develop the 13 national level hydropower bases and various small hydropower stations to ensure a steady increase of hydropower at certain level of growth rate, and orderly develop new hydropower base in southeastern Tibet at proper time;

Wind power: move forward with the development of large wind power bases in the three North areas and coastal areas in an orderly manner, accelerate the development of scattered wind energy resources in inland areas; actively and properly promote offshore wind power development, and develop offshore wind power in deeper waters far offshore in the long term;

Solar power: build large PV power stations in western China; promote distributed PV power generation in urban and rural areas advance CSP industrialization' and promote the diversified utilization of solar power generation so that PV and CSP power will see large-scale utilization and become main power sources;

Biomass power: actively and efficiently develop power generation from various biomass fuel sources, and comprehensively promote the efficient and clean utilization of biomass resources;

Geothermal and ocean energy: establish experimental and demonstrative projects, and complete commercially-oriented projects that are larger in scale than experimental and demonstrative projects. The larger projects will play an important role in special regions and areas.

Fully Promote Renewable Energy Heating and Fuel Use

Solar heating: promote the utilization of low-temperature solar thermal energy in large urban and rural areas and demonstrate the utilization of medium-high temperature solar thermal energy;

Biomass heating: promote the use of biogas, briquette fuel and various urban-rural wastes (industrial organic wastewater, excrements of livestock, etc.), and utilize various biomass resources in a comprehensive and efficient way;

Geothermal energy for heating: widely advance the direct utilization of shallow layer geothermal energy and promote the large-scale application of ground source heat pumps; and

Electricity heating: conduct pilots and demonstrations based on regional heating supplies.

3 Major Actions of Power Sector

Build a New-Type of Grid Public Service Platform

Power sector participants will build a cross-provincial and cross-regional main power grid, an advanced power distribution network and smart grid in a scientific manner, and develop a comprehensive service-driven power grid. Power sector participants will also establish an electricity scheduling platform that has advanced technologies, integrates work closely related to power forecasting, real-time scheduling operations and concentrated monitoring of transformer devices, and realizes full-process optimization and the multi-domain coordination of the scheduling of wind power and other new energy sources. Another goal for the power sector is to boost the function of the power grid to develop from a traditional power transmission and distribution network into a comprehensive service-driven power grid platform with a mix of power transmission, resource allocation, and interactive services; actively develop smart micro grids, and build a smart power distribution network that adapts to high levels of distributed power generation; and build a comprehensive service-driven power grid platform featured by the integration of two-way power transmission and interactive services.

Optimize the Deployment, Structure and Operation of Flexible Power

The power sector will optimize and run power generated from conventional energy sources; control the size of coal power and gradually turn to backup and peaking power sources; optimize and develop various flexible power sources on a large scale; build natural gas power generation;, fully tap into the regulating capacity of CSP, geothermal power generation and nuclear power in the long term; coordinate the layout and operation of hydropower projects, wind farms, PV power stations and other traditional power sources and grids, and promote the complementary operation of wind/hydro energy, wind/gas, and other diversified generating technologies.

Develop Demand Response Mechanisms and Energy Storage in a Large Scale

Power sector participants will develop adjustable load and continuously expand the scale of adjustable load to make it the most important flexible resource; arrange and construct a batch of pumped storage hydro power stations; make power grid operation safer, more stable and economical; avoid accidents; vigorously develop new energy storage measures, including advanced batteries, compressed air energy storage and electric vehicles; and promote the development and use of advanced energy storage technologies.

4

Joint Actions of the Society Broadly

Transform Energy Development Mindset Concept and Make Everybody a Renewable Energy Prosumer

China will undertake a publicity campaign aimed at encouraging citizens to respect and protect nature. The people shall also accept that developing renewable energy is the only way to truly realize the sustainable utilization of natural resources and ecological and environmental friendly energy development. The society shall also firmly seize on the historical opportunity of the new round of energy revolution and the Third Industrial Revolution. The country shall capture the development opportunity from integrated distributed energy production and utilization, increased electrification rate in energy end-use, and "Internet Plus". Everyone shall promote the production and utilization of clean renewable energy through joint actions, starting with waste classification, treatment and utilization, rooftop PV systems, electric vehicles and vehicle-network integration. Citizens should also become energy prosumers, so that everybody contributes to and benefits from energy production and consumption. China will fully enter into a new energy era with such major features as a green, low-carbon, clean, efficient, and smart grid that successfully incorporates high penetration renewable energy.

Promote Application of Renewable Energy Heating and Solar PV Power in to Residential and Commercial Buildings

China intends to popularize and install solar water heaters across the board; expand renewable energy heating and refrigeration systems to make renewable energy a major supplemental energy source for residents and businesses hot water, heat supply and refrigeration; and promote building rooftop and building integrated PV power generation. Renewable energy will become one of the major energy sources of residents and businesses in terms of hot water, heat supply and refrigeration. Roof-mounted PV system and new building integrated PV systems will be advocated on a large scale.

Promote Electrification and Renewable Energy Heating in Industry Sectors

Some industrial sectors will be pushed to boost scientific and economic power alternatives; promote the large-scale application of renewable energy heating utilization technology in industries with lower requirements for the quality of heat energy, such as printing and dyeing, and the textile and food industries; facilitate the utilization of renewable energy heat in industrial sectors with higher requirements for the quality of heat energy, including electricity, iron & steel, and chemical industries, so that it will become an important energy source of heat supply in industrial sectors. Power alternatives and the application of renewable energy heat utilization technology will be fully realized to replace conventional fossil fuel energy on a large-scale.

Promote Electrification in Transportation Sector to Increase Valley Load and Improve System Flexibility Through Energy Storage

Electric vehicles will be popularized and extended on a fast track so that they will enjoy application on a certain scale before 2020; the role of base load will be preliminary, and millions of kw of base load and flexible resources will be formed by 2030.

Build Urban Renewable Energy System and Energy Internet

China will actively demonstrate and promote development of smart buildings, smart residential communities, micro grids, and integrated energy networks; build an advanced smart energy internet through integration of the energy system, Internet of Things, and Internet; integrate various types of energy-consuming facilities of the industry, building and transportation sectors with the power grid, gas pipelines as well as local distributed energy such as solar energy, wind power and geothermal energy; transform various kinds of renewable energy and fossil energy into multiple energy forms such as cooling, heating and electricity according to demand of end users, and put in place a smart energy internet featuring sustained production of clean energy and intelligent allocation of energy resources.

Major Actions of Government, Renewable Energy Industry, Power Sector, and the Society Broadly

		Before 2017	2020	2030	2050
GOVERNMENT	(I) Formulate and Implement Clean Low-Carbon Energy Revolution Strategy and Action Plan, Which Prioritize Renewable Energy	Formulate energy revolution strategy and action plan for 2030 and develop vision and goals for 2050.	Make coal consumption and coal power installed capacity peak by 2020; CO_2 emission peak between 2020 and 2025.	Fossil energy consumption reach peak and begin to decline; renewable energy replace the stocks of fossil energy.	Renewable energy meet 60% of energy demand and 80% of electricity demand; CO_2 emission decrease sharply.
	(II) Establish Power Market Mechanism Adaptable to Renewable Energy Development	Deregulate power sales market; establish renewable power priority dispatch mechanism; make power trading centers independent from grid.	Establish competitive bidding market, multi-part tariff, cross-provincial and cross-regional power trading market; promote the separation of power transmission and distribution networks.	Set up a modern electric power market system under the support of the smart grid.	Form a 21st - century electricity market that is open to everyone.
	(III) Improve the Green Tax System and Carbon Trading Market System to Create A Fair Playing Field for Renewable Energy	Levy resource tax and environmental tax; and use the fund collected to support renewable energy development.	Build up carbon trading market; start to allocate carbon emission permits through auction; and levy carbon taxes.	Fully implement the allocation of carbon emission permits through auction	Complete formation of a green tax system and a carbon market system.
	(IV) Establish Sound Systems of Legal Protection, Comprehensive Management and Professional Regulation Adaptable to Development of Renewable Energy	Revise Electricity Law, strengthen power system planning, and expand investment access; modernize regulatory system.	Promulgate Energy Law, improve Renewable Energy Law, and build a regulatory system in coordination with the market-oriented reform.	Build sound systems of legal protection, comprehensive management and professional regulation.	Form new-type energy management system
RENEWABLE ENERGY INDUSTRY	(I) Build Major Public R&D Platforms and Technology Innovation System	Design innovation-oriented technology roadmap; build public platforms for resource assessment, technology R&D and testing for renewable energy such as wind power and solar power.	Basically build up wind power and solar power technology system; average levelized cost of wind power and solar power reduce to less than RMB0.5/kWh and RMB0.6 /kWh.	Grasp advanced integrated application technology of renewable energy; wind power and solar power generation are fully economically competitive.	Build world leading renewable energy technology and industrial system.
	(II) Keep Sustained Large-scale Development of Renewable Power Generation	Build a batch of demonstration projects (or zones) of offshore wind power and distributed solar PV power.	Straighten out hydropower development mechanism to realize steady development; accelerate the development of both centralized and distributed wind power and solar power.	Fully develop hydropower and roof –top PV power; accelerate the pace of wind power and solar power development in North China, Northwest, and Northeast.	Fully realize the diversified utilization of various types of renewable power generation technologies; the proportion of renewable power generation exceed 80%.
	(III) Fully Promote Renewable Energy Heating and Fuel Use	Develop demonstrations of solar heating, biomass heating, and geothermal heating technology and innovative business models.	Promote the utilization of medium-low temperature renewable energy heat; promote the commercialized demonstration of advanced biofuel technology.	Promote the utilization of medium-high temperature renewable energy heat in industrial and commercial fields.	Fully popularize the utilization of low-temperature solar heat and meet the heat demand of all buildings and some industrial users.
POWER SECTOR	(I) Build a New-Type Grid Public Service Platform	Develop demonstrations of smart grid and micro grid; promote integrated utilization of wind power and solar PV power forecast system; construct inter-regional power transmission lines.	Fully promote smart grid; build advanced power dispatch platform, and realize large-scale, hierarchical integrated and optimal dispatch.	Vigorously promote micro grid; build smart distribution grid suitable for high penetration of distributed generation.	Establish a comprehensive service-oriented grid platform integrating two-way transmission and interactive services.
	(II) Optimize the Deployment, Structure, and Operation of Flexible Power	Control and optimize the layout of coal power development in eastern area; speed up the construction of pumped hydro storage and natural gas power stations; improve the regulating capacity of coal power (including combined heat and power generation).	Fully control the scale of coal power; expand the scale of pumped hydro storage and natural gas power; tap the regulating capacity of coal power, concentrating solar power, and nuclear power.	Change coal power into standby and peaking capacity; coal power and gas power become major adjustable power sources; all kinds of power supply have the ability of adjustment.	Fully establish a diversified and flexible power system.
	(III) Develop Demand Response Mechanisms and Energy Storage in a Large Scale	Develop demonstrations of adjustable load and demand response; develop pumped hydro storage; demonstrate advanced energy storage technology.	Expand the scale of adjustable load; promote application of advanced energy storage technology on the user side.	Fully tap the potential of adjustable load; popularize advanced energy storage technology.	Demand response and energy storage become important flexible resources.
IV. JOINT ACTIONS OF THE WHOLE SOCIETY	(I) Transform Energy Development Mindset and Make Everybody a Renewable Energy Prosumer	Enhance communications with the general public to let them fully recognize that renewable energy is the only road to a clean energy future	Everyone should take actions to promote the production and utilization of renewable energy.	Energy users become energy producers and consumers (prosumer).	Realize a new situation that everyone enjoys, every family sells and everybody benefits from energy.
	(II) Promote Application of Renewable Energy Heating and Solar PV Power in Residential and Commercial Buildings	Speed up the development of building roof-top and building integrated PV power; build demonstration projects (or zones) of renewable energy hot water, heating and cooling in residential and commercial buildings.	Scale up renewable energy heating and cooling system; fully promote roof-top PV system and building integrated PV system.	Fully promote renewable energy heating and cooling system; new buildings are mandated to install building integrated PV system.	Renewable energy dominate residential and commercial heating and cooling.
	(III) Promote Electrification and Renewable Energy Heating in Industry Sector	Develop demonstrations in printing and dyeing, textile, and food industries of using electricity and renewable energy heating to replace fossil energy	Promote large-scale application of using electricity to replace primary energy consumption and using renewable energy for heating in printing and dyeing, textile, and food industries.	Promote the utilization of renewable energy heat in such industrial sectors with higher requirement for the quality of heat supply, including electricity, iron & steel and chemical industries.	Fully popularize the use of electricity and renewable energy heating to replace fossil energy on a large scale
	(IV) Promote Electrification in Transportation Sector to Increase Valley Load and Flexible Energy Storage	Promote electric vehicle development and encourage charging during valley load period.	Electric vehicles have reached a certain scale, and contribute to increasing valley load.	Fully promote electric vehicles and form a valley load of about 100 million kW.	Popularize electric vehicles and provide a valley load of more than 1 billion kW.
	(V) Build Urban Renewable Energy System and Smart Energy Internet	Develop demonstrations of micro grid and integrated energy network in buildings, communities, or regions to realize integrated utilization of renewable energy, electricity, gas, and district heating.	Develop demonstrations of urban integrated clean energy network that mixes the energy supply service for residents, businesses, industries, and transportation sectors, and experiment smart energy Internet.	The energy network, Internet of Things and the Internet couple to form an "energy Internet".	Fully develop smart energy Internet.

China 2050 High Renewable Energy Penetration Scenario
and Roadmap Study

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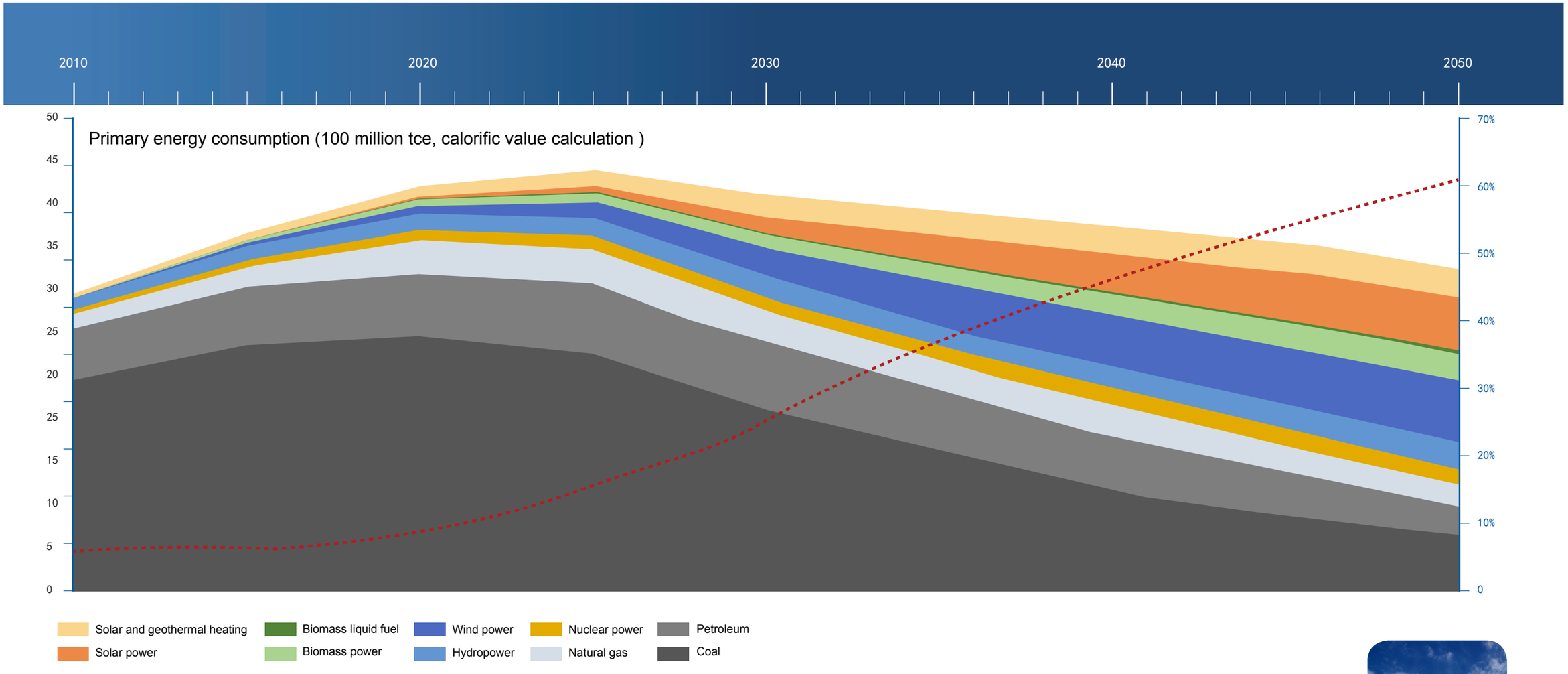

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