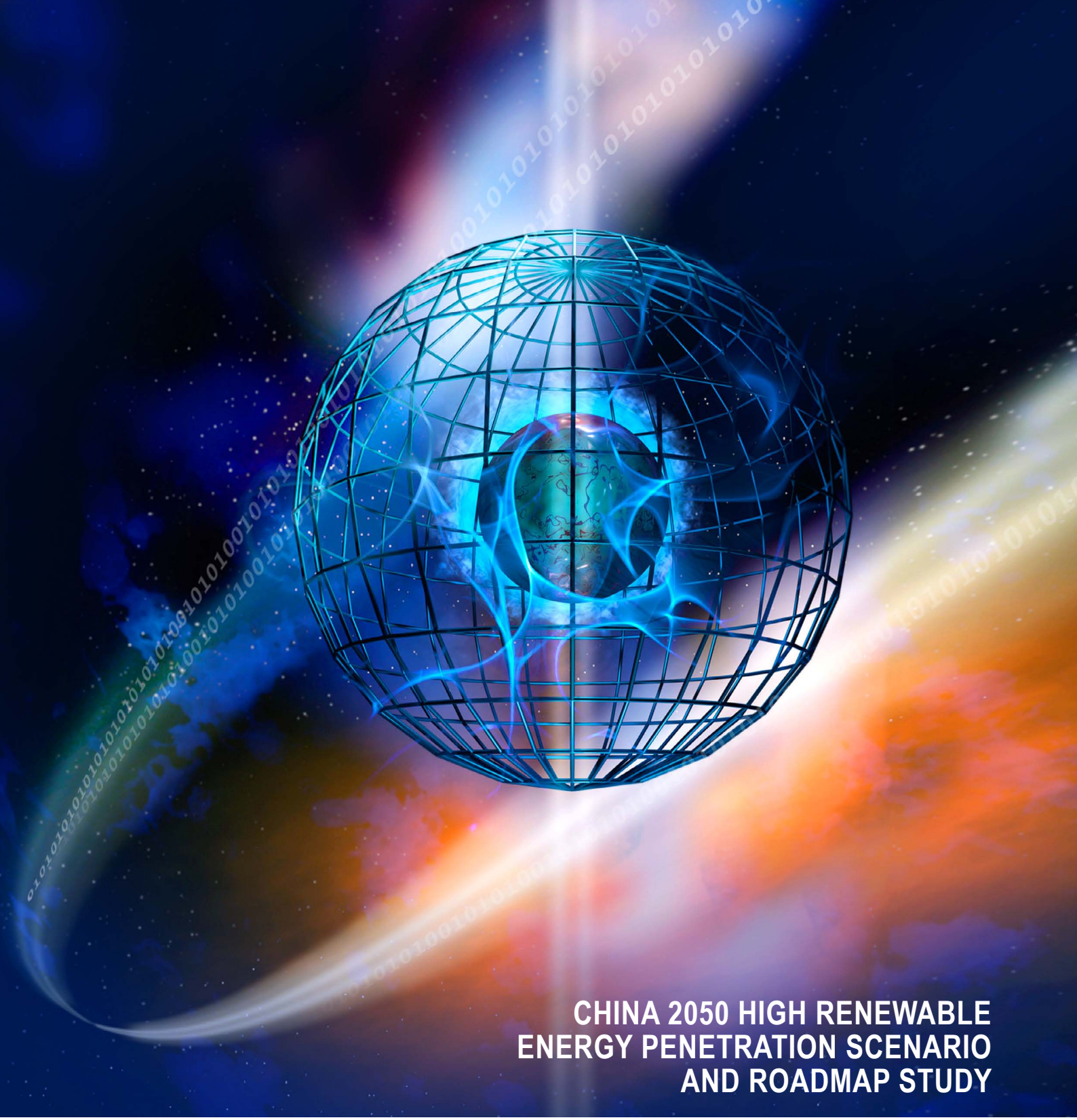

CHINA 2050 HIGH RENEWABLE ENERGY PENETRATION SCENARIO AND ROADMAP STUDY

ENERGY FOUNDATION
能源基金会

ENERGY RESEARCH INSTITUTE
NATIONAL DEVELOPMENT AND REFORM COMMISSION

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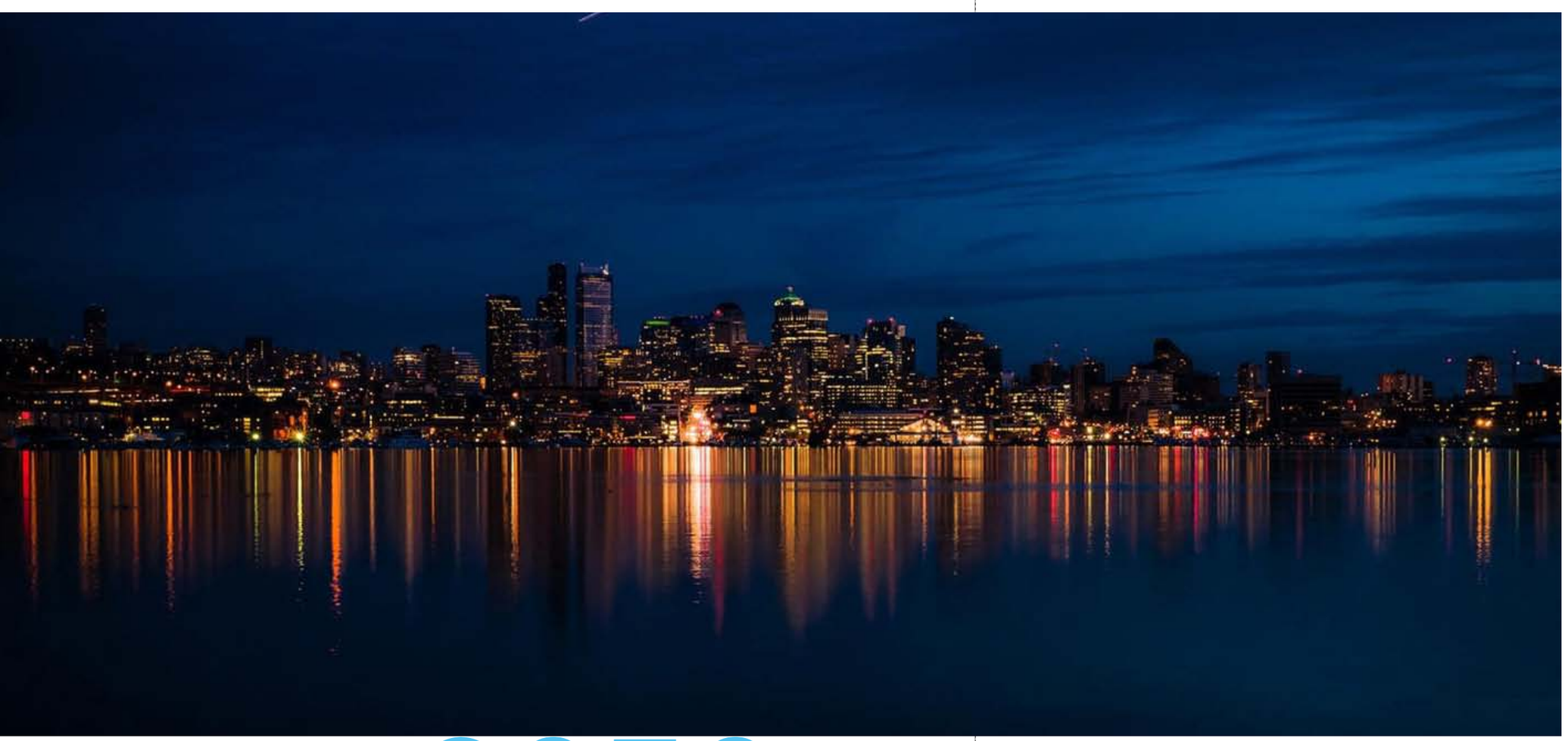


2050

HIGH RENEWABLE ENERGY PENETRATION SCENARIO: VISION AND CONSENSUS

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.

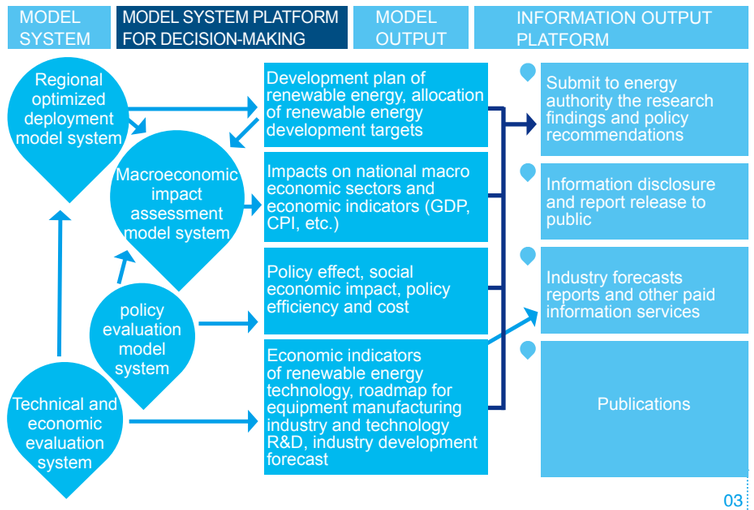
—Milan Kundera

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.

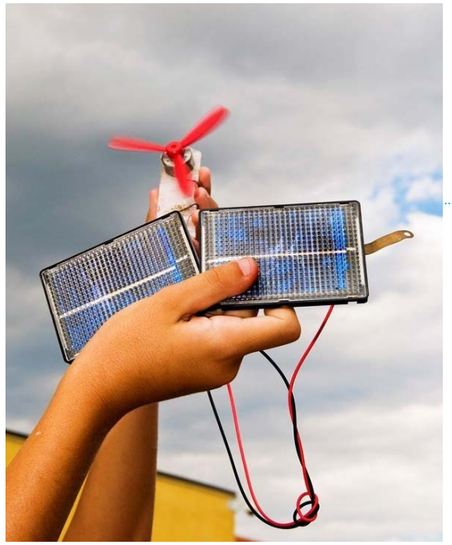
The international community has reached a consensus that high renewable energy penetration is a critical part of the efforts to tackle climate change and control temperature rise below 2 degrees. Europe and America have been first in taking the meaningful step of providing blueprints. As the world's largest developing country, largest coal consumer, and largest emitter of greenhouse gases, China is confronted with challenges that are more urgent and arduous as it transforms toward clean, low-carbon energy. "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. This vision will help advance the goal of a "Beautiful China" with the development level of medium-income countries, clear water and blue skies.

The study takes high renewable energy penetration as the goal and greenhouse gas emissions and air pollutants as basic constraints; it conducts technical and economic evaluation, power system production simulation, social and economic impact evaluation, etc., and based on these optimizes renewable energy deployment pathways under different scenarios as well as puts forward corresponding implementation schemes. Results show that a high renewable energy penetration scenario in 2050 is both technically and economically feasible, in which renewables account for over 60% in China’s total energy consumption and over 85% in total electricity consumption – signifying a true revolution of energy production and consumption.

Figure 1 Model Cluster



HIGH RENEWABLE ENERGY PENETRATION SCENARIO: PATHWAY



1

By 2050, Renewable Energy Could Meet More Than 60% of Primary Energy Demand

In a high renewable energy penetration scenario where over 60% of end-use energy consumption is electricity, the energy system in 2050 is highly efficient, with energy efficiency 90% higher than in 2010. By that time, primary energy consumption is 3.4 billion tons of coal equivalent, and renewable energy accounts for 62%.

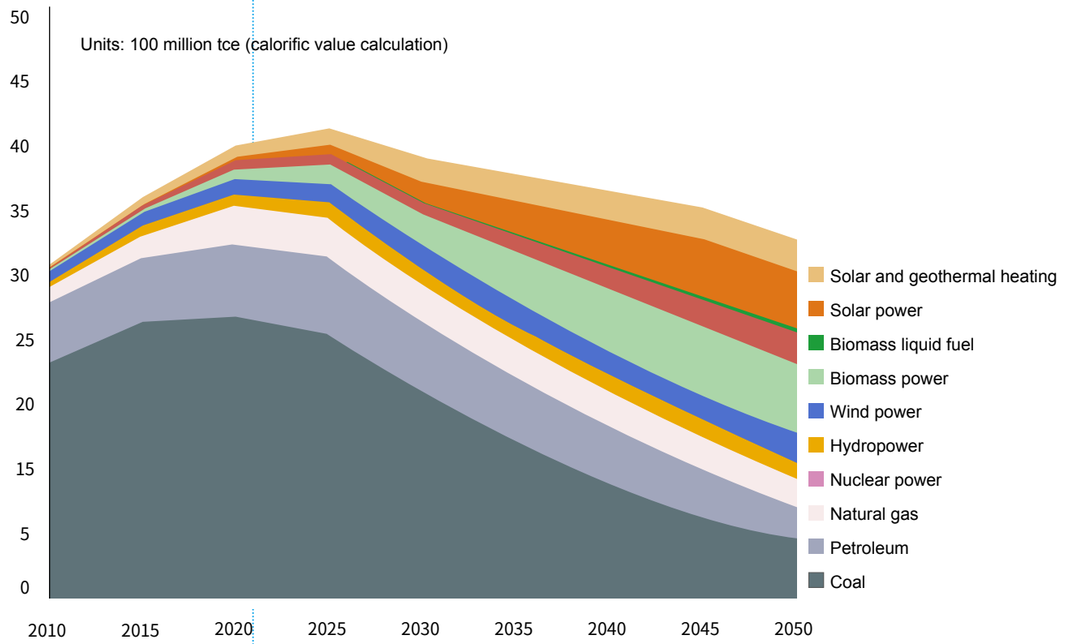


Figure 1 China's Primary Energy Consumption

2

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

Under the high renewable energy penetration scenario, coal consumption will be effectively controlled and the coal consumption peak can be reached by 2020. The consumption peak of fossil energy will be realized by 2025, and thereby reaching the goal of peaking greenhouse gas emissions by 2030 will be assured and most likely to happen as early as by 2025.

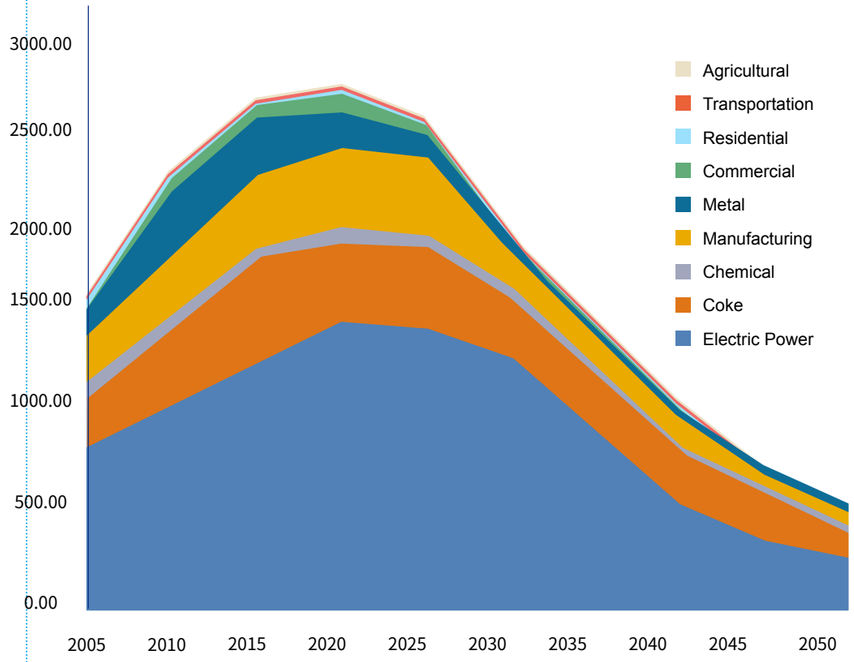
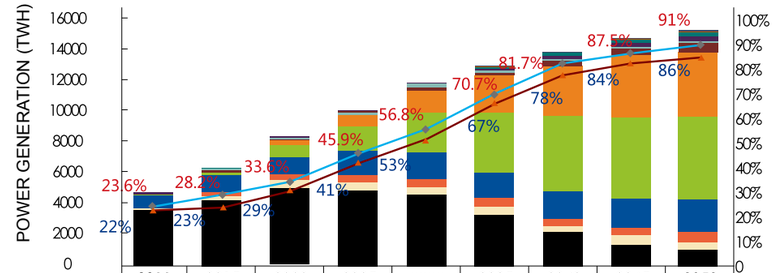


Figure 2 China's Coal Consumption by Sector in High Penetration Scenario (million tce)

3

Renewable Power is the Essential Replacement for Fossil Energy

By 2050, the national total power generation will be 15.2 trillion kWh, 86% of which will be renewable power and 91% non-fossil energy, while coal power drops to below 7%.



	2011	2015	2020	2025	2030	2035	2040	2045	2050
Ocean energy						4	4	4	4
Geothermal power						30	90	90	90
Wood 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 3 Power Generation in High Penetration Scenario

4

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

Through technological breakthroughs, cost reductions as well as the comprehensively deepening of power sector reforms, between 2020 and 2040, wind and solar power will develop rapidly, with an average of annual newly installed capacity of close to 100 million kW. 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 will account for 64% of China's total power generation and will become the main power source of the future green electricity system.

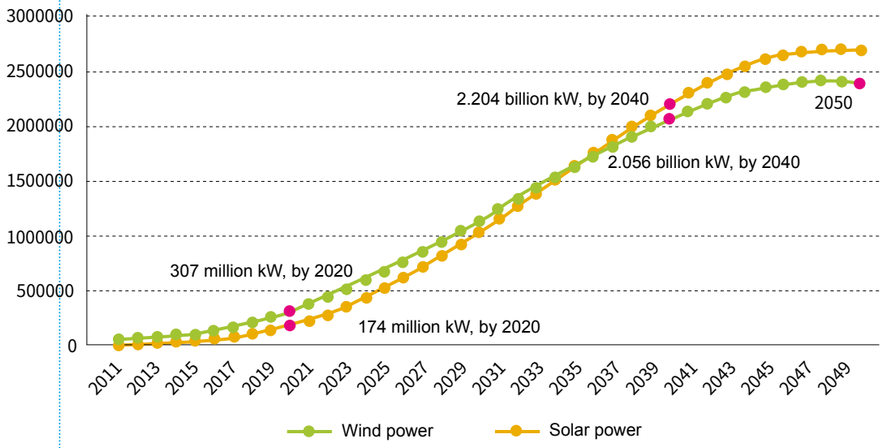


Figure 4-1 Development Phase Diagram of Wind and Solar Power Generation in High Penetration Scenario

Various areas of the country will have the ability of developing wind power and solar power on a large scale, laying equal emphasis on centralized and distributed development.

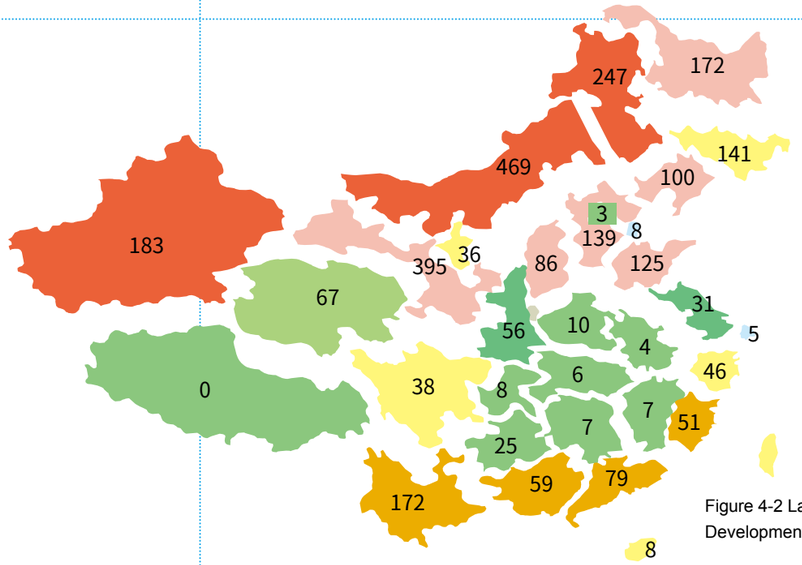


Figure 4-2 Layout of Wind Power Development in 2050 (GW)

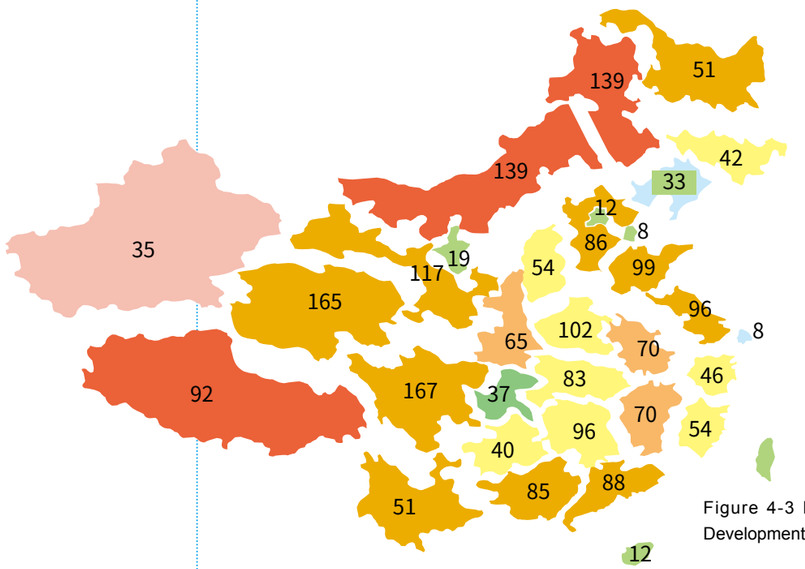


Figure 4-3 Layout of Solar Power Development in 2050 (GW)

5

Higher Electrification Rate Will Enable Renewable Energy to Grow to a Higher Level

By 2050, China's end-use energy consumption will reach 3.2 billion tons of coal equivalent, of which electricity will account for 60%, 36 percentage points higher than that of 2010. Electricity will become the main form of energy for people's production and living.

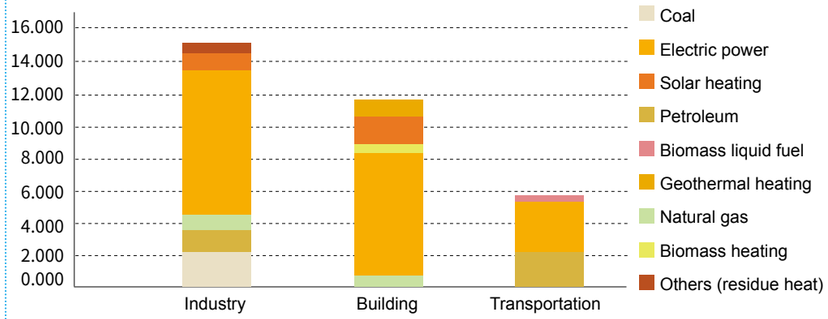


Figure 5-1 Electricity Consumption by Sector

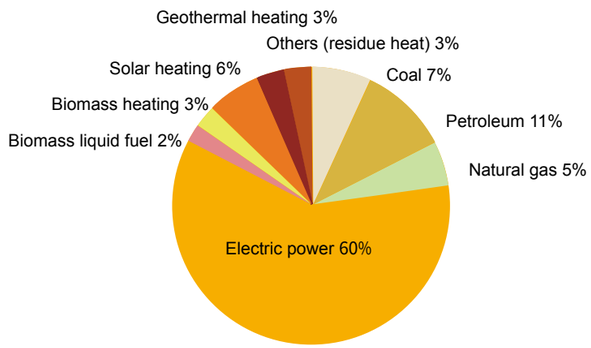


Figure 5-2 Share of Electricity in End-Use Energy Consumption

6

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

With the increase of renewable power generation, we need to expand the transmission infrastructure in order to integrate renewable energy in a larger geographical area. Regional interconnection and expansion of the balancing area is helpful to reduce the changes in net load. There will be three cross-regional transmission lines with a gross capacity of more than 100 million kW, respectively, the Northwest-Central China line, Central China-East China line and North China-East China line.

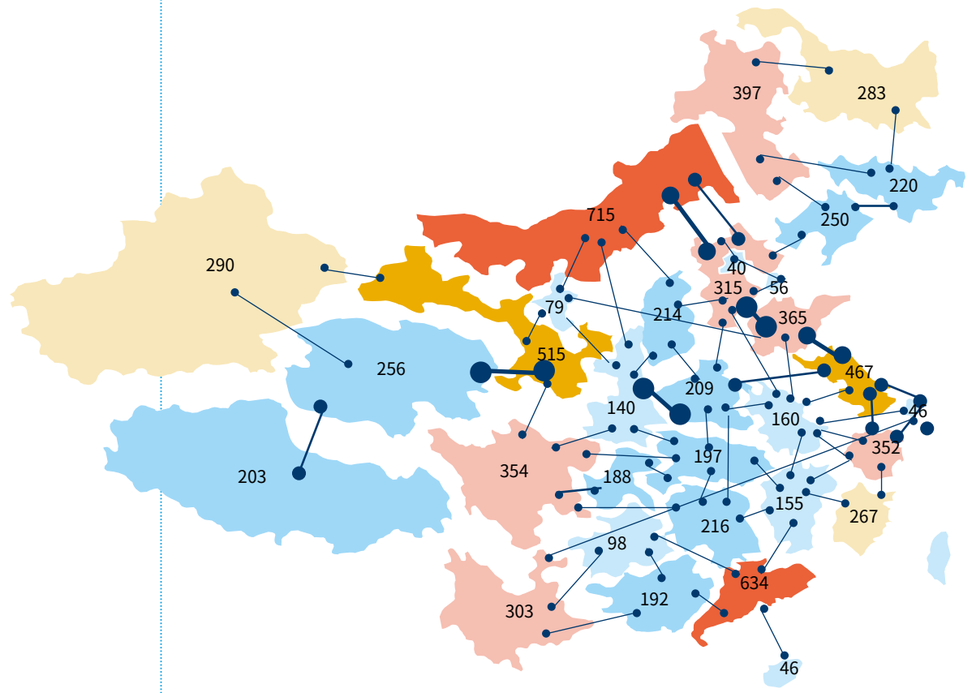


Figure 6 Inter-provincial Transmission Capacity Demand and the Total Installed Capacity of Each Province (GW) in High Penetration Scenario

7

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

The contribution of variable power will rise from 30% to 60% in high penetration scenario as compared with in reference scenario, making it more challenging to ensure the real-time balance between electricity supply and demand. Variability and uncertainty associated with high-penetration wind power and solar power will be managed through increasing power trading in market, adding flexible generation capacity, improving the flexibility of coal power, using energy storage technology and demand response mechanism, as well as expanding transmission infrastructure.

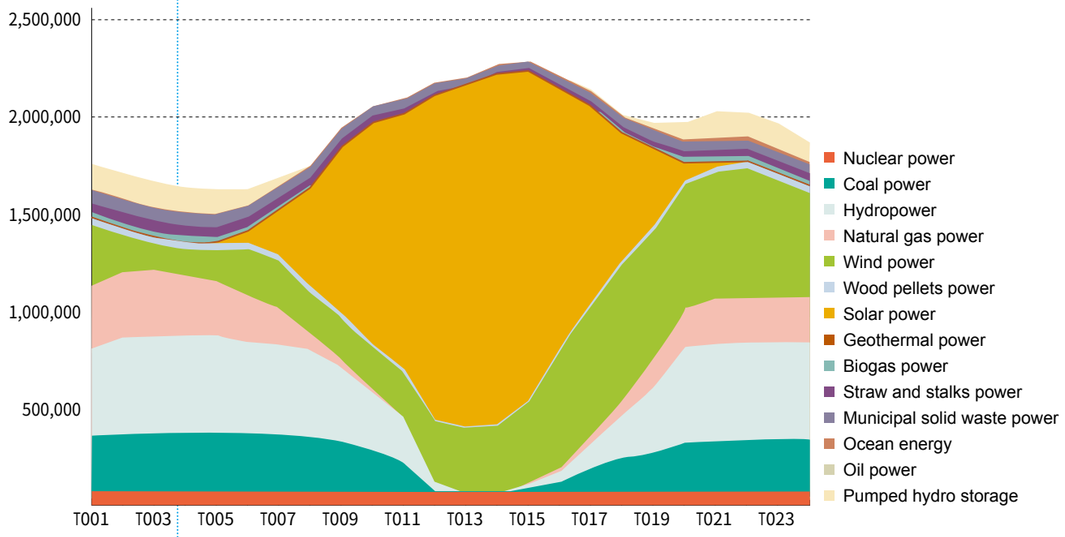
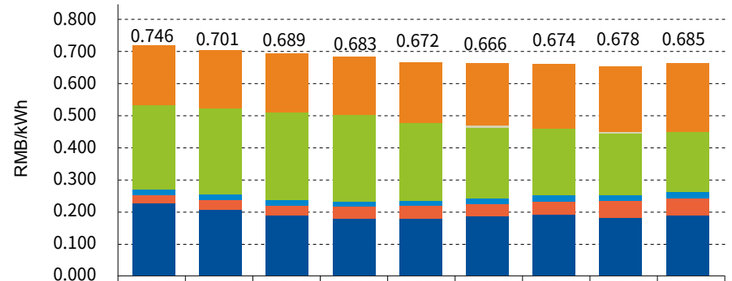


Figure 7 Analysis of the Hourly Dispatch of Nationwide Power Generation on a Typical Day in High Penetration Scenario

8

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

In the high renewable energy penetration scenario, the average cost of electricity will rise slightly between 2030 and 2050, basically remaining between RMB0.672/kWh and RMB0.685 yuan/kWh. Most of the incremental capital investment of the high penetration scenario will be offset by saving the fuel cost of fossil energy which would otherwise happen in the reference scenario, and China could realize a high penetration scenario with a small or non incremental cost.



	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
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 8 Trend of kWh Cost Development in High Penetration Scenario

9

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

Emerging industries like wind power, solar power, and electric vehicle will become a new economic growth point. In 2050, the added value of renewable energy industries will grow to RMB17 trillion, making a contribution of 6.2% to the GDP of that year. The added value of electric vehicle industry will grow to close to RMB 8 trillion, accounting for 2.9% of the GDP.

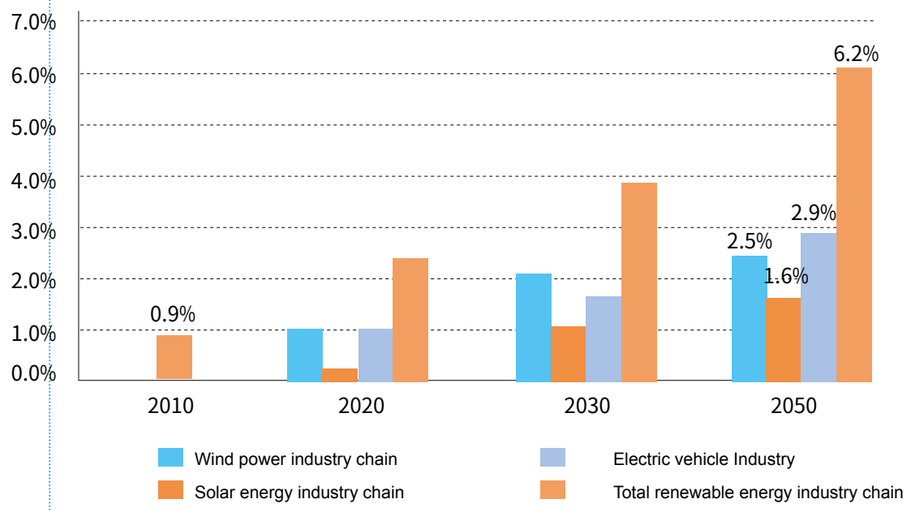


Figure 9-1 Contribution of Renewable Energy and Related Industries to GDP

The high renewable energy penetration scenario will create 12 million jobs in 2050 in the renewable energy and related industries, which will promote the transmission of China's employed population from traditional manufacturing to high value add industries.

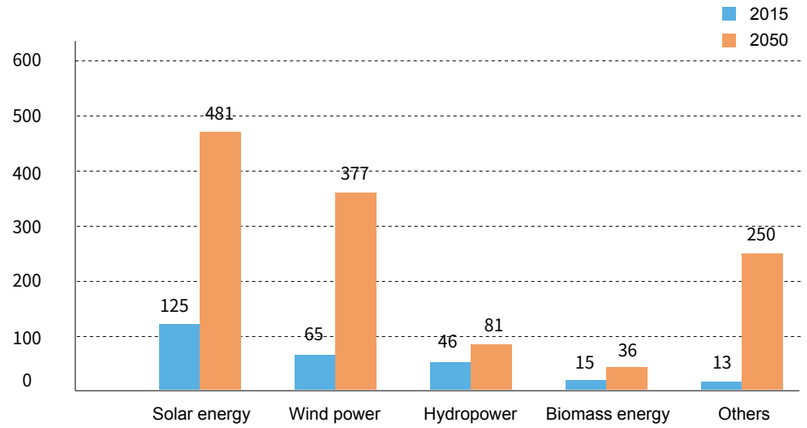


Figure 9-2 Growth of Employment in Renewable Energy and Related Industries (Unit: 10 Thousand)

10

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

Major pollutants and CO_2 emitted by the combustion of fossil fuel will decrease significantly. The emissions of major pollutants (SO_2, NOx, mercury, etc.) in 2050 will hold the line of that in 1980. The emissions of CO_2 will decrease to 3 billion tons, making outstanding contributions to slowing down global climate change.

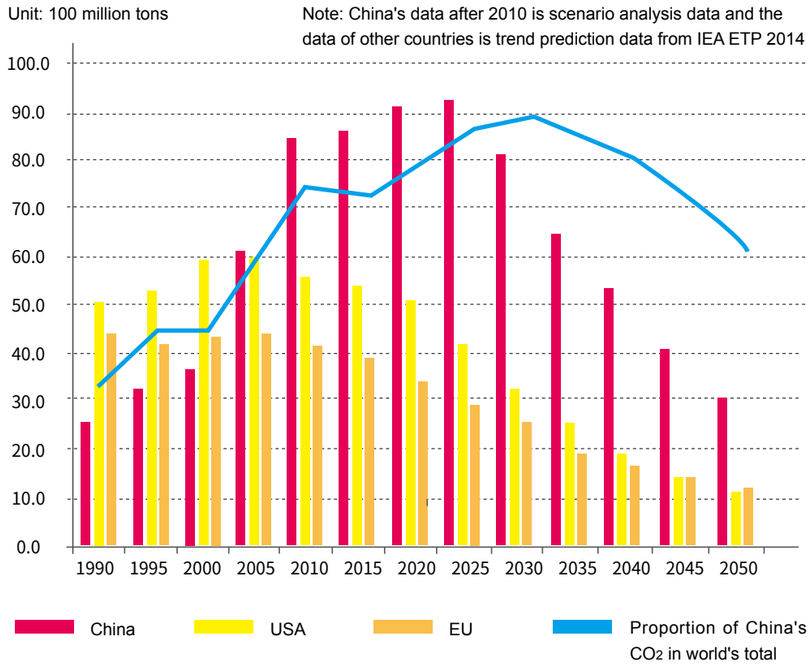


Figure 10-1 China's CO_2 Emission in the Global Contrast in High Penetration Scenario

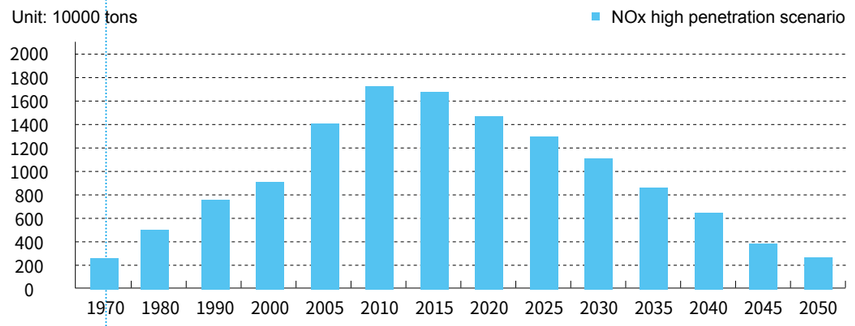


Figure 10-2 China's NOx Emission in High Penetration Scenario

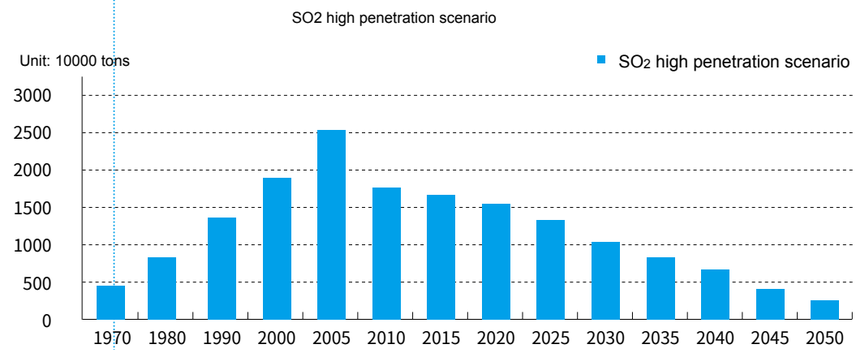
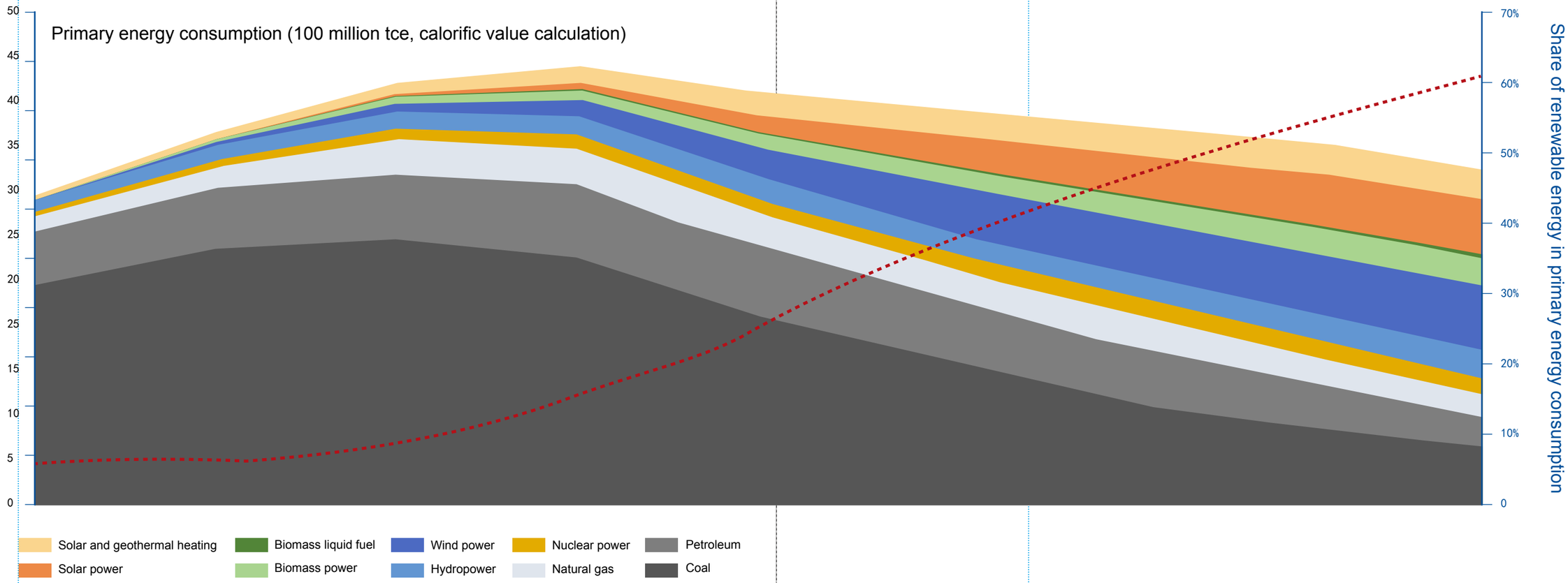


Figure 10-3 China's SO_2 Emission in High Penetration Scenario

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 That Is Suitable for 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 That Are Suitable for the 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 Layout, 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 on 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.

2010 2020 2030 2040 2050



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TECHNICAL SUPPORT